Deschutes Basin
HABITAT CONSERVATION PLAN

STUDY REPORT
Study 11 – Phase 1: Identification and Evaluation of Existing IFIM and Other Data for Application to the DBHCP

Prepared for:

Deschutes Basin Board of Control, and
City of Prineville, Oregon

Prepared by:

R2 Resource Consultants, Inc.
and
Biota Pacific Environmental Sciences, Inc.

March 2013

DESCHUTES BASIN HABITAT CONSERVATION PLAN

STUDY REPORT

Study 11 – Phase 1: Identification and Evaluation of Existing IFIM and Other Data for Application to the DBHCP

Prepared for:

Deschutes Basin Board of Control
P. O. Box 919
Madras, Oregon 97741

City of Prineville
387 NE Third Street
Prineville, Oregon 97754

Prepared by:

R2 Resource Consultants, Inc.
P. O. Box 203
Redmond, Washington 98073

Biota Pacific Environmental Sciences, Inc.
P. O. Box 158
Bothell, Washington 98041

March 2013

TABLE OF CONTENTS

1.0 Introduction 1

1.1. Background 1

1.2. Purpose, Scope, and Methods 1

2.0 Results 4

2.1. Reach Descriptions 4

2.1.1. Deschutes River – Big Falls to Lake Billy Chinook (RM 132 – RM 120) 4

2.1.2. Deschutes River – Pelton Re-regulating Dam to the Mouth of the Deschutes River (RM 100 – RM 0.0) 11

2.1.3. Whychus Creek – Plainview Ditch to the Mouth of Whychus Creek (RM 25.8 – RM 0.0) 14

2.1.4. Crooked River– Bowman Dam to the Crooked River Diversion (RM 70.5 – RM 57.0) 19

2.1.5. Crooked River – Prineville Valley Reach; Crooked River Diversion to NUID Pumps (RM 57.0 – RM 27.6) 23

2.1.6. Crooked River – NUID Pumps to Highway 97 (RM 27.6 – RM 18.0) 28

2.1.7. Ochoco Creek – Ochoco Dam to the Mouth of Ochoco Creek (RM 10.5 – RM 0.0) 31

2.1.8. McKay Creek – Jones Dam to the Mouth of McKay Creek (RM 5.8 – RM 0.0) 35

2.1.9. Lytle Creek – Ochoco Main Canal to the Mouth of Lytle Creek (RM 5.0 – RM 0.0) 39

2.2. Available Data Sets 44

2.2.1. Crooked River Reaches 44

2.2.2. Deschutes River Reaches 48

2.3. Data Gaps 49

2.3.1. Deschutes River – Big Falls to Lake Billy Chinook (RM 132 – RM 120) 49

2.3.2. Deschutes River – Pelton Re-regulating Dam to the Mouth of the Deschutes River (RM 100 – RM 0.0) 50

2.3.3. Whychus Creek – Plainview Ditch to the Mouth of Whychus Creek (RM 25.9 – RM 0.0) 50

2.3.4. Crooked River– Bowman Dam to the Crooked River Diversion (RM 70.5 – RM 57.0) 50

2.3.5. Crooked River – Prineville Valley Reach; Crooked River Diversion to NUID Pumps (RM 57.0 – RM 27.6) 51

2.3.6. Crooked River – NUID Pumps to Highway 97 (RM 27.6 – RM 18.0) 51

2.3.7. Ochoco Creek – Ochoco Dam to the Mouth of Ochoco Creek (RM 10.5 – RM 0.0) 52

2.3.8. McKay Creek – Jones Dam to the Mouth of McKay Creek (RM 5.3 – RM 0.0) 52

2.3.9. Lytle Creek – Ochoco Main Canal to the Mouth of Lytle Creek (RM 5.0 – RM 0.0) 52

2.4. Assessment Tools 52

2.4.1. Wetted Perimeter 54

2.4.2. Toe-Width Method 58

3.0 Recommendations 62

3.1. Assessment Tool Recommendations 62

3.2. Reach Prioritization Recommendations 64

4.0 References 66

Appendices 72

Appendix A – IFIM Study Transect Data 72

Appendix B – Wetted Perimeter Relationships at Various Reaches. 77

Appendix C – Washington State Department of Ecology Toe-Width Regression Curves for covered fish species. 83

Appendix D – Toe-Width Relationships at Key Reaches. 84

LIST OF TABLES

Table 1-1. Stream reaches where the effects of DBHCP covered activities and covered fish species coexist. 3

Table 2-1. Habitat and substrate composition in the Deschutes River reach between Steelhead Falls and Big Falls. 8

Table 2-2. Habitat and substrate composition in the Crooked River reach between Lone Pine Bridge and Peoples Diversion. 25

Table 2-3. Percent of ODFW stream segments in the Prineville Valley Reach that do not meet the Low Fish Passage Design Flows of 0.5 and 1.0-ft maximum water depth at a river discharge of 32 cfs. 27

Table 2-4. McKay Creek peak flows. 37

Table 2-5. Crooked River reaches with available IFIM/PHABSIM study data. 44

Table 2-6. Example of rearing habitat changes at different flow levels on 7.8 miles of the Deschutes River between the Pelton Reregulating Dam and Trout Creek using a Wetted Perimeter approach. 49

Table 2-7. Seasonal species and life-history stage priority for application of the Toe-Width-WUA Regression Method. 61

Table 3-1. Stream reaches with instream flow data gaps. 63

LIST OF FIGURES

Figure 2-1. Map of Deschutes River Basin showing stream reaches evaluated in this study. 5

Figure 2-2. Map of Stream Reach 1 of the Deschutes River between Big Falls and Lake Billy Chinook. 6

Figure 2-3. Monthly flow duration curves for the Deschutes River near Culver gage #14076500..... 10

Figure 2-4. Map showing locations of stream reaches predicted by the UCM model to produce primarily the steelhead (blue) or resident redband (red) life history form of *Onchorynchus mykiss*. 10

Figure 2-5. Map of Stream Reach 2 of the Deschutes River between Pelton Reregulating Dam and Trout Creek..........12
Figure 2-6. Monthly flow duration curves for the Deschutes River near Madras gage # 14092500...13
Figure 2-7. Map of Stream Reach 3 from the Plainview Ditch to the mouth of Whychus Creek. 15
Figure 2-8. Whychus Creek Restoration Project, Camp Polk Meadow Preserve. 16
Figure 2-9. Monthly flow duration curves for Whychus Creek near Sisters gage #14075000. 17
Figure 2-10. Map of Stream Reach 4 of the Crooked River from Bowman Dam to the Crooked River Diversion..........20
Figure 2-11. Monthly flow duration curves for the Crooked River near Prineville Gage # 14080500...21
Figure 2-12. Map of Stream Reach 5 of the Crooked River from the Crooked River Diversion to NUID pumps. 24
Figure 2-13. Crooked River RM 42.8 – RM 43.2 showing changing channel activity due to high localized groundwater table. 27
Figure 2-14. Map of Stream Reach 6 of the Crooked River from the Crooked River Diversion to NUID pumps. 29
Figure 2-15. July mean flows at Opal Springs and at Terrebonne and the difference between the two gages, 1967 to 1973..........30
Figure 2-16. Map of Stream Reach 7 from Ochoco Dam to the mouth of Ochoco Creek. 33
Figure 2-17. Monthly flow duration curves for the Ochoco Creek below Ochoco Reservoir Gage # 14085300..........34
Figure 2-18. Longitudinal water temperature profile for Ochoco Creek from its mouth at the Crooked River to Ochoco Reservoir-July 2005. 34
Figure 2-19. Map of Stream Reach 8 from Jones Dam to the mouth of McKay Creek..........36
Figure 2-20. Map of Stream Reach 9 from Ochoco Main Canal to the mouth of Lytle Creek. 40
Figure 2-21. WUA vs. flow for juvenile Chinook salmon and steelhead trout rearing in the Upper Canyon Segment..........45
Figure 2-22. WUA vs. flow for Chinook salmon and steelhead trout spawning in the Upper Canyon Segment..........45
Figure 2-23. WUA vs. flow for juvenile Chinook salmon and steelhead trout rearing in the Prineville Valley Segment. 46
Figure 2-24. WUA vs. flow for Chinook salmon and steelhead trout spawning in the Prineville Valley Segment. 46
Figure 2-25. WUA vs. flow for juvenile Chinook salmon and steelhead trout rearing in the Lower Canyon Segment. 47
Figure 2-26. WUA vs. flow for Chinook salmon and steelhead trout spawning in the Lower Canyon Segment..........47
Figure 2-27. An example of a relationship between wetted perimeter and flow for a stream riffle cross-section showing upper and lower inflection points. 55

Figure 2-28. Example of the incremental change in wetted perimeter (feet) with flow at cross-section (NSO #18) in the Upper Canyon Reach of the Crooked River downstream of Bowman Dam. 55

Figure 2-29. Example of the incremental change in wetted perimeter (feet) with flow at cross-section (NSO #BF-3) in the Prineville Valley Reach of the Crooked River downstream of the Crooked River Diversion........ 56

Figure 2-30. Example of the incremental change in wetted perimeter (feet) with flow at riffle cross-section (NSO #56-1) in the Lower Canyon Reach of the Crooked River downstream of the NUID Pumping plant. 56

Figure 2-31. Incremental change in wetted perimeter (feet) with flow at rating curve transect 1 in the Deschutes River nr Culver, OR........ 57

Figure 2-32. Incremental change in wetted perimeter (feet) with flow at rating curve transect 1 in the Deschutes River nr Madras, OR........ 57

Figure 2-33. Regression equation for toe-width of stream versus peak WUA of steelhead trout spawning........ 59

LIST OF PHOTOGRAPHS

Photo 1. Steelhead Falls on Deschutes River at RM 127........ 7

Photo 2. Crooked River Canyon........ 30

Photo 3. Lytle Creek lowermost check-dam structure at RM 0.5 (July 11, 2012). Q = 4.4 cfs. 39

Photo 4. Lytle Creek downstream of the Crooked River Distribution Canal at RM 3.0 (May 26, 2005). 41

Photo 5. Lytle Creek at approximately RM 0.3 downstream of railroad crossing (July 11, 2012). .. 42

Photo 6. Lytle Creek upstream of the check-dam at RM 0.5 (July 11, 2012). 42

List of Acronyms, Symbols and Abbreviations

Acronym, Symbol, Abbreviation	Definition
@	At
Ac-Ft	Acre-feet
AID	Arnold Irrigation District
Alt	Alternative
App.	Appendix/Appendices
Approx.	Approximate
AV	Approach Velocity (fps)
Bdg	Bridge
BFW	Bank Full Width
BiOP	Biological Opinion
BLM	United States Bureau of Land Management
BMPs	Best Management Practices
BOD	Biochemical Oxygen Demand
BPA	Bonneville Power Administration
ºC	Degrees Celsius
CCI	Construction Cost Index
CFR	Code of Federal Regulations
cfs	Cubic feet per second
cm	Centimeter
COCO	Central Oregon Cities Organization
COIC	Central Oregon Intergovernmental Council
COID	Central Oregon Irrigation District
Cr	Creek
CRK	Crooked River
CREP	Conservation Reserve Enhancement Program
CRSO	Crooked River at Smith Rocks; Hydromet Gauge #14087300 code
CRWC	Crooked River Watershed Council
CTWS	Confederated Tribes of Warm Springs
Cu Ft	Cubic Feet
CWA	Clean Water Act
D	Drain
DBBC	Deschutes Basin Board of Control
DBHCP	Deschutes Basin Habitat Conservation Plan
DEQ	Oregon Department of Environmental Quality
DES	Deschutes River
DO	Dissolved oxygen
DRC	Deschutes River Conservancy
DWA	Deschutes Water Alliance
$	Dollar
DN	Downstream Passage Alternative
d/s	Downstream
Ecology	Washington State Department of Ecology
eds.	Editors
EF	East Fork
e.g.	exempli gratia; For Example

Acronym, Symbol, Abbreviation	Definition
EL.	Elevation
ENR	Engineering News Record
EPA	United States Environmental Protection Agency
ESA	Endangered Species Act
et al.	And others
etc.	et cetera; and so on
Eval.	Evaluation
ºF	Degrees Fahrenheit
FEMA	Federal Emergency Management Agency
f/m^2	Fish per square meter
FERC	Federal Energy Regulatory Agency
FS	Forest Service
FSC	Floating Surface Collector
‘	Foot
ft	Feet
Ft^2	Square Feet
FTE	Full Time Equivalent
fps	Feet per second
gal	Gallon
GIS	Geographic Information Systems
GBD	Gas Bubble Disease
GBT	Gas Bubble Trauma
gpm	Gallons per minute
>	Greater than
≥	Greater than or equal to:
GW	Groundwater
HDQrs	Headquarters
HCP	Habitat Conservation Plan
HEC-RAS	Hydrologic Engineering Center-River Analysis System
Hwy	Highway
his	Habitat Suitability Index
“	Inch
in.	Inch
I.D.	Inside Diameter
IFIM	Instream Flow Incremental Methodology
IHA	Indicators of Hydrologic Alteration
ITP	Incidental Take Permit
kg	Kilogram
kWh	Kilowatt-hour
LASAR	Laboratory Analytical Storage and Retrieval Database
Lb	Pound
LiDAR	Light Detection And Ranging
LYT	Lytle Creek
<	Less than
≤	Less than or equal to:
M	Meter
M^2	Square Meter
mm	Millimeter

Acronym, Symbol, Abbreviation	Definition
max	Maximum
MCK	McKay Creek
Mg	Milligram
mg/L	Milligrams/liter
min	Minimum
MLCO	Mill Creek nr Schoolhouse; Hydromet Gauge #14083400 code
MP	Mile Post
mpg	Miles per gallon
MSL	Mean Sea Level
#	Number
N	North
No.	Number
NA	Not Applicable
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPCC	Northwest Power and Conservation Council
NPDES	National Pollutant Discharge Elimination System
Nr	Near
NRCS	Natural Resources Conservation Service
NUID	North Unit Irrigation District
O & M	Operation and Maintenance
0+ age	Juvenile fish – less than a year in age
OAR	Oregon Administrative Rule
OCH	Ochoco Creek
OCRO	Ochoco Creek blw Marks Creek; Hydromet Gauge #14082550 code
OCHO	Ochoco Creek blw Reservoir; Hydromet Gauge #14085300 code
ODA	Oregon Department of Agriculture
ODEQ	Oregon Department of Environmental Quality
ODFW	Oregon Department of Fish and Wildlife
ODOT	Oregon Department of Transportation
OID	Ochoco Irrigation District
OR	Oregon
OSU	Oregon State University
OWEB	Oregon Watershed Enhancement Board
OWRD	Oregon Department of Water Resources
%	Percent
P	Probability
p.	Page/pages
Pers. Comm.	Personal Communication
PGE	Portland General Electric
PHABSIM	Physical Habitat Simulation
POD	Point-of-Diversion
PROC.	Proceedings
PSE	Puget Sound Energy
Q	Discharge (cfs)
R.	River
R^2	Coefficient of Determination; Square of the Correlation Coefficient
r^2	Coefficient of Determination; Square of the Correlation Coefficient

Acronym, Symbol, Abbreviation	Definition
R2	R2 Resource Consultants, Inc.
RBT	Rainbow Trout
Rd	Road
Reclamation	United State Bureau of Reclamation
Res.	Reservoir
RM	River Mile
§	Section
SA	Surface Area (ft^2)
SA_e	Effective Surface Area (ft^2)
SC	Screen Contact
SID	Swalley Irrigation District
SOP	Standard Operating Procedure
STH	Steelhead Trout
SWCD	Soil and Water Conservation District
SWW	Selective Water Withdrawal
3D	Three Dimensional
TDG	Total Dissolved Gas
TID	Tumalo Irrigation District
TMDL	Total Maximum Daily Load
TR	Transect
TSID	Three Sisters Irrigation District
TSS	Total Suspended Solids
UCM	Unit Characteristic Method
UDLAC	Upper Deschutes Local Advisory Committee
UDWC	Upper Deschutes Watershed Council
ug	Microgram
UGB	Urban Growth Boundary
UP	Upstream Passage Alternative
US	United States
USACOE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USBR	United State Bureau of Reclamation
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
u/s	Upstream
VAF	Velocity Adjustment Factor
Vol.	Volume
vs.	Versus
VSP	Viable Spawning Population
w/	With
WF	West Fork
WHY	Whychus Creek
WP	Wetted Perimeter
WPN	Watershed Professional Network
WSE	Water Surface Elevation
WUA	Weighted Useable Area
Ww	Wetted Width

Acronym, Symbol, Abbreviation	Definition
WWTP	Wastewater Treatment Plant
XS	Cross Section
Yr	Year
Z	Depth

1.0 Introduction

1.1. Background

Seven central Oregon irrigation districts (Arnold, Central Oregon, North Unit, Ochoco, Swalley, Three Sisters, and Tumalo) and the City of Prineville, Oregon (City) are seeking Federal Endangered Species Act (ESA) incidental take permits for the bull trout (*Salvelinus confluentus*), Middle Columbia River steelhead (*Oncorhynchus mykiss*), Middle Columbia River spring Chinook salmon (*O. tshawytscha*), Deschutes River summer/fall Chinook salmon, Sockeye salmon (*O. nerka)* (collectively referred to as the covered fish species), and up to 10 other unlisted species inhabiting the Deschutes River basin. As required by Section 10 of the ESA, the City and the irrigation districts (collectively the Applicants) are preparing the Deschutes Basin Multi-species Habitat Conservation Plan (DBHCP) to minimize and mitigate the effects of the proposed incidental take on the covered species. The DBHCP is being prepared in cooperation with a multi-stakeholder Working Group representing the U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), U.S. Bureau of Reclamation (Reclamation), U.S. Bureau of Land Management (BLM), Oregon Department of Fish and Wildlife (ODFW), Oregon Department of Environmental Quality (ODEQ), Oregon Water Resources Department (OWRD), the Confederated Tribes of the Warm Springs, Crook County, and several non-governmental entities.

This study has been completed to support development of the DBHCP. The scope of work for the study was reviewed and approved by the Working Group prior to initiation. Drafts of this report are being provided to the Working Group for review and comment, and the final report will reflect their input. This report does not necessarily represent the consensus view of the Working Group. Rather, it is intended to serve as a reference document for the members of the group as they collaboratively develop plans for additional studies and conduct analyses of the effects of the covered activities and the benefits of various minimization and mitigation options.

1.2. Purpose, Scope, and Methods

The purpose of this study is to compile and evaluate existing data that may be used to support the evaluation of potential impacts and conservation measures related to the storage, release and diversion of irrigation water covered by the DBHCP on instream flows and habitats for covered fish species. Potential impacts on covered amphibians will be addressed in a separate study, currently being developed with USFWS. The information provided in this report will be used to select evaluation methods for the DBHCP from the available options. The selection of evaluation methods will be made on a reach-specific basis, and will consider the costs, benefits, and practical limitations of available methods, the nature and extent of anticipated effects (positive and negative) in each reach, and the importance of each reach to the covered fish species.

Some level of instream flow assessment has occurred at every mainstem river reach and in some tributary waters historically accessible to covered fish species in the Deschutes basin. Three mainstem reaches in the Crooked River Basin were evaluated using the Instream Flow Incremental Methodology (IFIM) / Physical Habitat Simulation (PHABSIM) study methods in 1993 and reassessed in 2001 (Hardin 1993, 2001). One mainstem Deschutes River reach between the Pelton Reregulating Dam and the confluence of Trout Creek was evaluated by

Portland General Electric (PGE 2001)using a wetted perimeter approach (Nelson 1980). The remaining reaches were reviewed using the Oregon Method in the early 1970s (Lauman and Pitney 1973). Most of these reaches have existing instream water rights established between 1983 and 1990, or water rights that are currently pending. Although instream flow water right claims have been established for mainstem waters throughout the basin, detailed hydraulic channel and flow data are no longer available for these reaches.

The selection of evaluation methods for the DBHCP will be dependent on the extent the existing information can be used to evaluate the flow-related effects (positive and negative) of covered activities and proposed conservation measures on the covered fish species and their habitats. The purpose of the DBHCP evaluation of instream flow levels will be to assess relative impacts and relative values of various proposed conservation measures, not to establish optimum flow levels for covered species.

Phase 1 of Study 11 compiles and reviews existing instream flow information to determine its sufficiency for use in evaluating such activities. Specifically, Hardin's 1993 and 2001 available data and instream flow models are evaluated for their applicability to the DBHCP. Instream flow data can be complex and it is important to complete a technical review of the data to determine the utility and reliability of the available information. Channel cross-sectional transects, representative habitat types and associated transect weightings, flow measurements, water surface elevations (WSEs), calibration methods, velocity adjustment factors (VAFs), and model data decks are evaluated. Based on the transect data, channel hydraulics including measured vs. simulated WSEs, Froude numbers, Manning's N, channel surface areas and wetted widths, average velocities, wetted perimeters, and hydraulic depths are calculated and graphed as a function of increasing river discharges within the calibration range of each study reach.

Projections of a relationship between habitat and instream flow levels for covered fish species will be used during DBHCP development to consider and compare various irrigation district operating scenarios. Flow information from Priority Studies 1, 7, and 13 will be used in the DBHCP to understand the existing surface water flow network and to assess existing impacts and future effects of the conservation measures on covered fish species. Cross sections of stream channels can help define hydrological characteristics of a site such as toe-width, bankfull width, wetted perimeter of the channel, and stream morphology characteristics regarding channel confinement. These characteristics will be useful in the DBHCP for approximating flow effects on covered fish species. An understanding of the unregulated, regulated (current), and proposed seasonal, monthly and daily flow variability at certain locations on the covered lands will serve as input to an instream flow assessment under the DBHCP.

This study focuses on stream reaches within the covered lands where the effects of the covered activities on flow coincide with the presence, or potential presence, of covered fish species. The covered lands include multiple reaches of the Deschutes, Little Deschutes and Crooked rivers as well as Crescent, Tumalo, Whychus, Ochoco, McKay, and Lytle creeks. Not all of these reaches currently support covered fish species, and many reaches are not expected to support covered fish species during the term of the DBHCP. This study is therefore limited to the nine reaches where covered activities could influence habitat for covered fish species through alteration of flow (Table 1-1).

Within the nine reaches, this study identifies key stream segments where habitat conditions may be evaluated. Selection of these segments was based on a combination of importance of the segment to covered fish species, sensitivity of the segment to the effects of the covered activities, and availability of existing flow and habitat data. Prioritizing the key stream segments for future evaluation will help focus the most detailed and costly studies on reaches with the greatest value to covered species and where information is lacking. Less detailed studies may be appropriate for lower priority stream segments.

Table 1-1. Stream reaches where the effects of DBHCP covered activities and covered fish species coexist.

No.	River Basin	Stream	Stream Reach	River Mile	Reach Codes
1	Deschutes	Deschutes River	Big Falls to Lake Billy Chinook	132 - 120	DES 9, 10
2	Deschutes	Deschutes River	Pelton Re-regulating Dam to Mouth[1/]	100 - 0.0	DES 1-7
3	Deschutes	Whychus Creek	Plainview Ditch to Mouth	25.8 - 0.0	WHY 1-6
4	Crooked	Crooked River	Bowman Dam to CRK R. Diversion[1/]	70.5 - 57.0	CRK 8 – 10
5	Crooked	Crooked River	CRK R. Diversion to NUID Pumps[1/]	57.0 - 27.6	CRK 4 – 7
6	Crooked	Crooked River	NUID Pumps to Hwy 97[1/]	27.6 - 18.0	CRK 3
7	Crooked	Ochoco Creek	Ochoco Dam to Mouth	10.5 - 0.0	OCH 1-7
8	Crooked	McKay Creek	Jones Dam to Mouth	5.3 - 0.0	MCK 1-6
9	Crooked	Lytle Creek	Ochoco Main Canal to Mouth	5.0 - 0.0	LYT 1-3

1) Stream Reach with Existing Instream Flow Data

2.0 Results

2.1. Reach Descriptions

As described in Section 1.2, the analysis of co-occurrence indicates potential flow effects and covered fish species coincide in nine stream reaches on the covered lands (Figure 2-1). Four of the nine reaches have existing instream flow study data as described in Section 2.2 *Available Data Sets* below. Reach descriptions follow in the subsequent sections.

2.1.1. Deschutes River – Big Falls to Lake Billy Chinook (RM 132 – RM 120)

2.1.1.1. Overview

This 12-mile section of the Deschutes River designated as Stream Reach 1 occurs downstream of Big Falls, the historical natural upstream fish passage barrier on the upper Deschutes River, at river mile (RM) 132 (Figure 2-2). A fishway was constructed at Big Falls in the 1920's with hopes of passing anadromous fish species, but no fish were observed attempting to pass the falls (Mathisen 1985 as cited in Nehlsen 1995). The reach also contains an additional migratory deterrent at Steelhead Falls located at RM 127. Historically, steelhead trout could negotiate this falls in high river flows during winter and early spring. A ladder was constructed in the adjacent bedrock at Steelhead Falls in 1922 and fish were able to move upstream for a number of years to access spawning gravel areas and spring-fed flows between Steelhead and Big falls (Nehlsen 1995). The ladder at Steelhead Falls was not efficient at transporting fish and high river flows between November and April were still required for successful passage, limiting the potential upstream access to primarily steelhead trout.

The reach occurs in the area of substantial groundwater returns to the mainstem river (Gannett et al. 2001). Whychus Creek, a west bank tributary, enters the Deschutes River within this reach at RM 123.1, approximately 3 miles upstream of Lake Billy Chinook. There are no covered activities or other dams or diversions within this reach, but river flow and water temperatures are influenced by upstream storage, release and diversion of irrigation water.

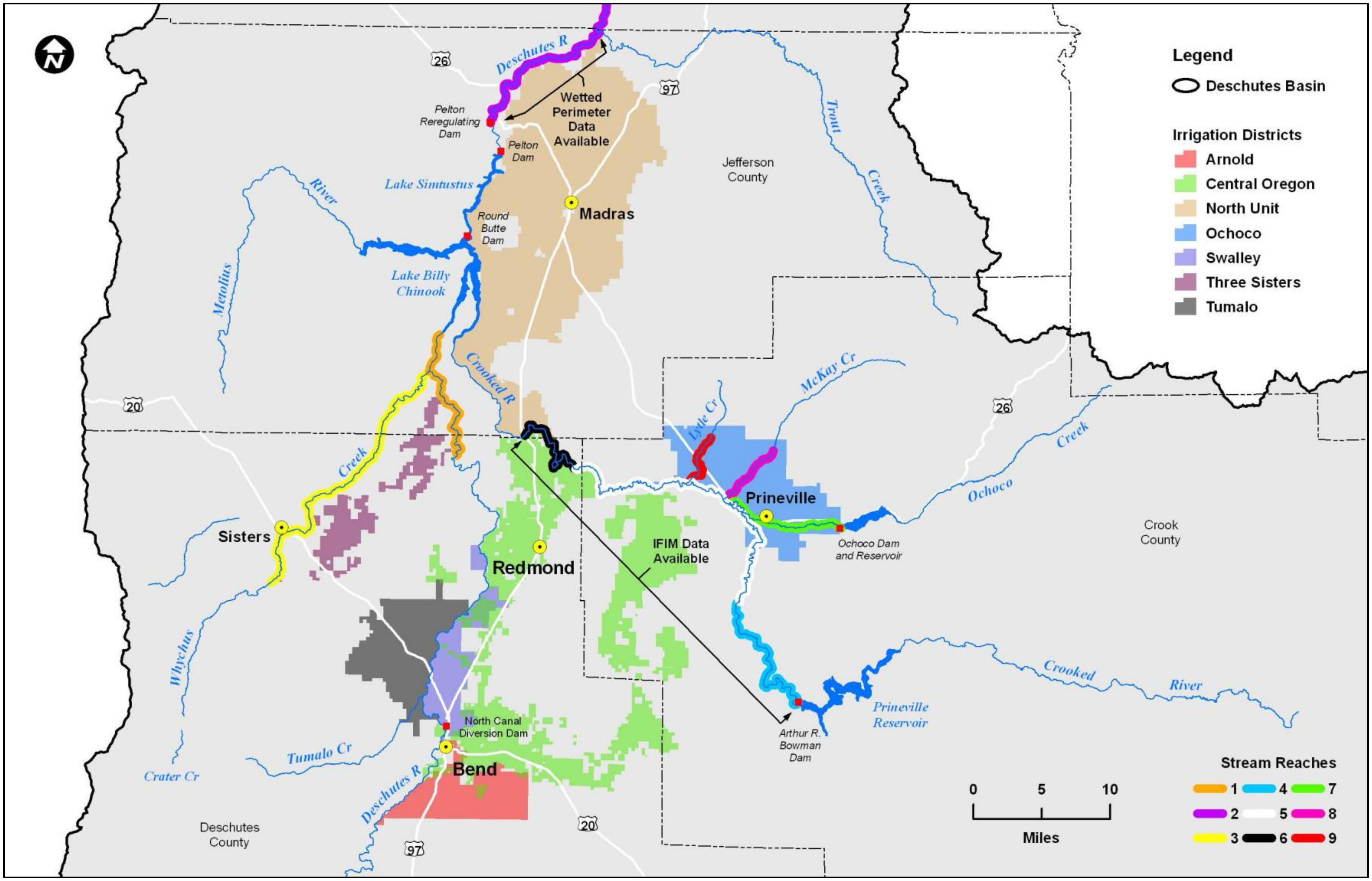


Figure 2-1. Map of Deschutes River Basin showing stream reaches evaluated in this study.

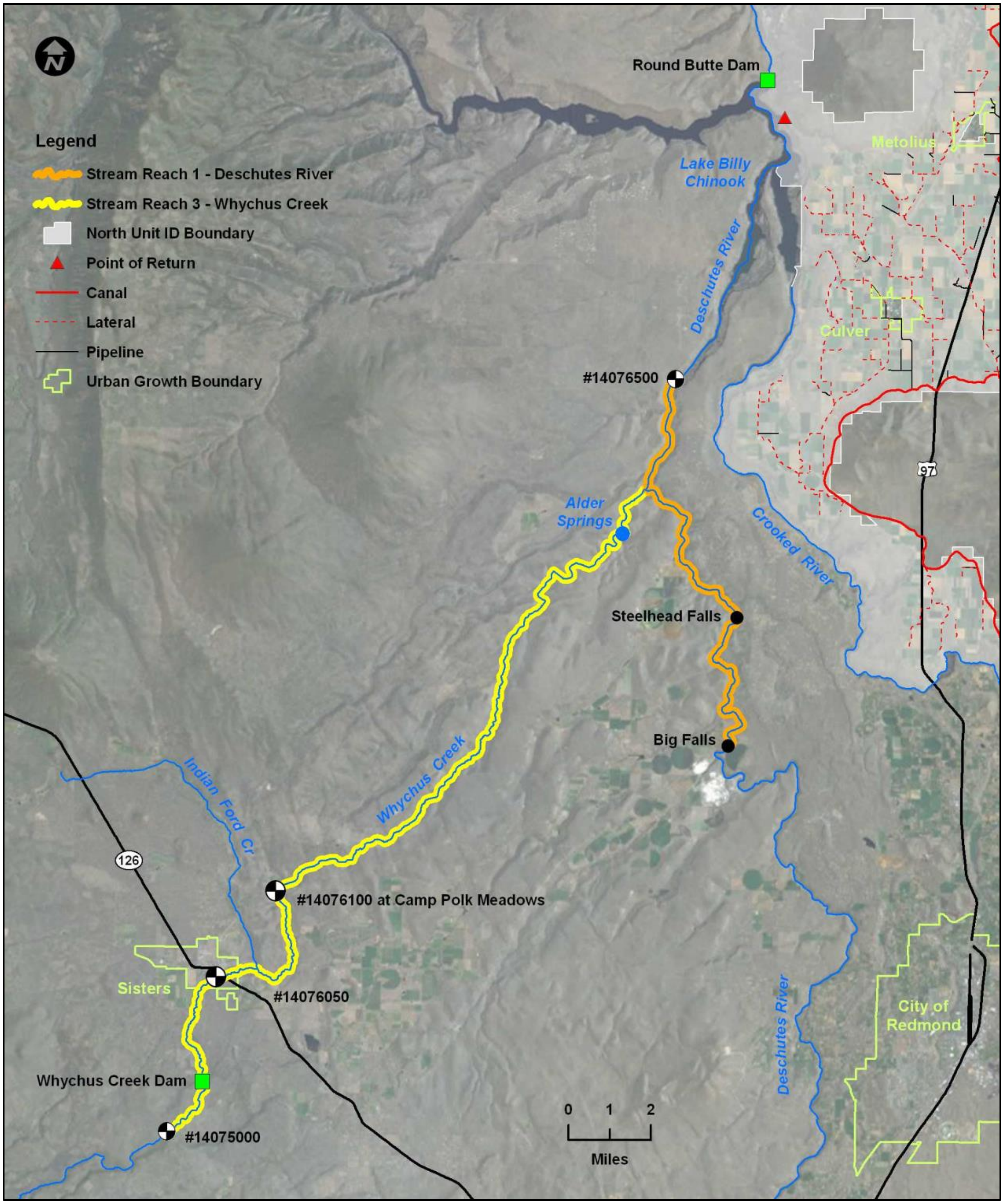


Figure 2-2. Map of Stream Reach 1 of the Deschutes River between Big Falls and Lake Billy Chinook.

2.1.1.2. Channel Characteristics

The Deschutes River flows through a deep, rugged, steep-walled basalt canyon in this reach. The well-defined canyon varies in width from a few hundred yards to 0.5 mile. Water and canyon depths increase as the river flows northward. The canyon gradually deepens to about 700 feet and becomes narrower near Lake Billy Chinook. The stream channel is stable and constrained over much of the reach, except for a few braided locations. Riparian vegetation includes willow, alder, mock orange, juniper, sedges, wild rose, red-osier dogwood, and other species (BLM et al. 1992; NPCC 2004). Riparian vegetation is thicker in areas where springs emerge from the canyon walls, and along river benches, islands, and tributary confluences.

The 5-mile portion of this reach from Steelhead Falls (RM 127) to Big Falls is constrained by steep (80%) and moderate v-shaped hill slopes (Photo 1). Average width of the active channel measured in 1993 was 109 feet, with a wetted width of 62 feet during summer low flow conditions (ODFW 1996). The stream gradient averaged 0.6 percent. Streambank stability was rated excellent since the channel is protected by non-erodible substrate and vegetation. Instream wood material during the ODFW (1996) survey was lacking. Pools through this section averaged 8.6 feet in depth. Habitat areas and streambed substrate composition were likewise recorded during the ODFW survey (Table 2-1).

Photo 1. Steelhead Falls on Deschutes River at RM 127.
Source: Gannett et al. 2001

Table 2-1. Habitat and substrate composition in the Deschutes River reach between Steelhead Falls and Big Falls.

Habitat Area		Percent (%)
Pool		29
Riffle		37
Glide		19
Other		15
Substrate Composition	**Size-Class Diameter**	**Percent (%)**
Bedrock		18
Boulder	> 12.0 in.	23
Cobble	≤ 12.0 in.	28
Gravel	≤ 3.0 in.	16
Sand and silt	≤ 0.1 in.	15

Source: AIP data (ODFW 1996)

The AIP habitat and substrate composition definitions are in accordance with Moore et al. (1997) as shown below:

Pool = Full or nearly full channel width area of deep, low velocity water scoured by forces generated from or dammed by channel structures. Water surface slope of zero.

Riffle = Fast, turbulent, shallow water over submerged or partially submerged gravel or cobble substrate.

Glide = An area of generally uniform depth and velocity with no surface turbulence. Glides may have some small scour areas but are differentiated from pools by their overall homogeneity and lack of structure. Generally deeper than riffles with few, if any, major flow obstructions and low habitat complexity.

Pocket = Pocket Water includes riffles with numerous (> 20% of unit area) pockets of small-sized pools created by scour associated with small boulders, wood, and streambed obstructions.

2.1.1.3. Flow Characteristics

River flows in this reach are recorded at the Deschutes River gage at Culver (USGS # 14076500). This gage picks up tributary inflow between Bend and Culver, including Tumalo and Whychus Creeks, and multiple surface water expressions of groundwater entering the Deschutes River between the Lower Bridge and Steelhead Falls (RM 133 to RM 128). The river gains a substantial amount of flow from groundwater releases in this reach. Watershed Sciences and MaxDepth Aquatics (2008) report 16 spring-fed sources between Big Falls and the inlet to Lake Billy Chinook that increased water flow rates. Gannett et al. (2001) estimated approximately 400 cfs are discharged from groundwater flow into the river before it enters Lake Billy Chinook. During the summer of 2001, Watershed Sciences and MaxDepth Aquatics (2008) measured approximately 500 cfs of groundwater infusion in this reach. Monthly flow exceedance curves for the Culver gage are shown in Figure 2-3.

2.1.1.4. Fish Habitat

Instream habitat remains in good condition in the Deschutes River from Big Falls to Lake Billy Chinook. Spawning gravel recruitment is naturally limited and is lacking below Steelhead Falls, but good gravel exists in the area above Steelhead Falls (Riehle 1999). Large boulders provide structural diversity in this reach of the Deschutes River.

Using HabRate methods for qualifying life history stage habitat conditions to produce spring Chinook salmon in accordance with ODFW protocols (Burke et al. 2003), Spateholts (2008) indicated this reach is fair for egg to fry survival, fair to poor for fry to parr survival, and good for parr to smolt survival, with an estimated smolt capacity of 5,664 outmigrating spring Chinook smolts.

Similarly, following the work of Ackerman et al. (2007), Spateholts (2012) used the Unit Characteristic Method (UCM) to estimate the summer steelhead parr production capacities. This reach was estimated to produce 58,526 summer parr, all of which were predicted to be of the resident life history form (Figure 2-4). Based on the stable river flows and relative cool water temperatures, this reach has been delineated as primarily producing resident redband trout (Zimmerman and Reeves 2000; Ackerman et al. 2007; Spateholts 2012). In a generic sense, these authors suggest stable flow regimes that provide cool temperatures while maintaining depth and velocities necessary to sustain adult rainbow trout throughout the summer and fall seasons will result in increased resident rainbow trout populations and decreased steelhead trout abundance, compared to reaches with seasonally warmer and less stable river flows.

2.1.1.5. Key Reach Segments

The 5-mile segment between Steelhead Falls and Big Falls likely contributes the best quality spawning habitat for steelhead trout and for Chinook salmon within the overall 12-mile reach. Spawning for steelhead occurs during the spring months between March and May, whereas Chinook salmon spawning occurs in fall between September and October. Spawning, incubation, and early life history rearing for both species could occur seasonally in this segment when water temperatures are favorable for such activities (Watershed Sciences and MaxDepth Aquatics 2008).

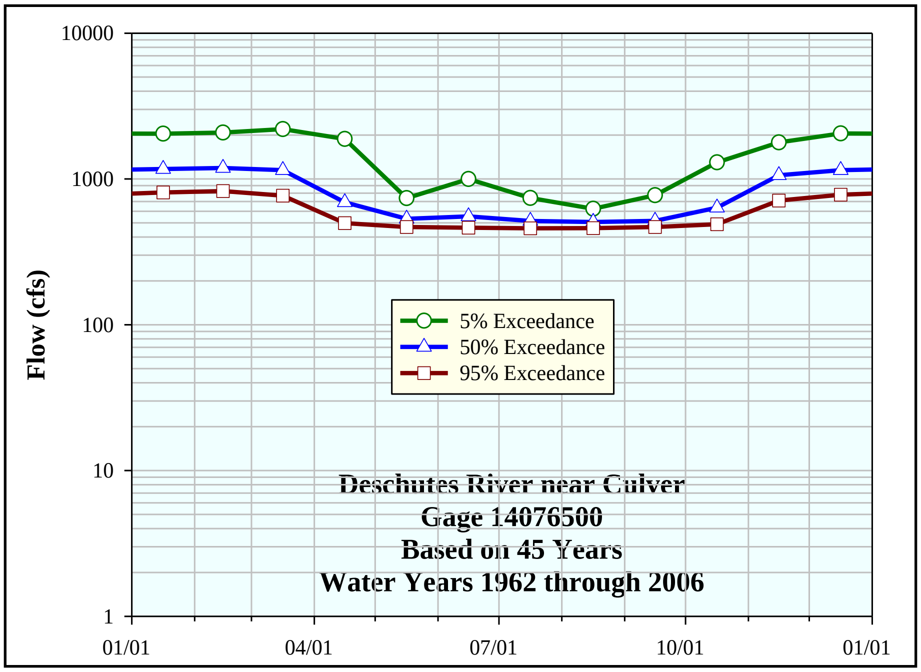


Figure 2-3. Monthly flow duration curves for the Deschutes River near Culver gage #14076500.
Source: USGS/OWRD data

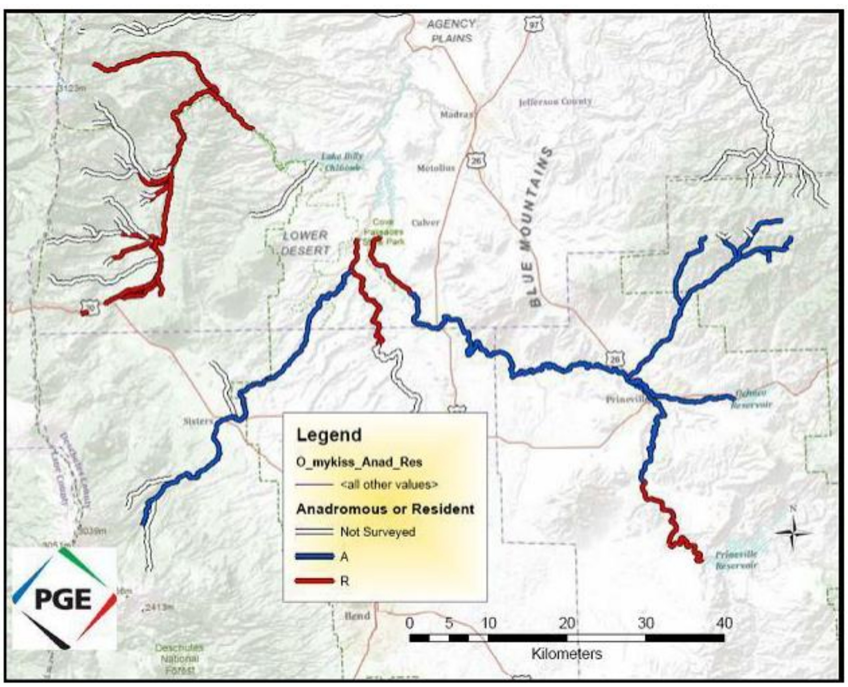


Figure 2-4. Map showing locations of stream reaches predicted by the UCM model to produce primarily the steelhead (blue) or resident redband (red) life history form of *Onchorynchus mykiss*.
Source: Spateholts (2012).

Based on longitudinal increases in groundwater inputs, water volumes and surface water temperatures continually improve in the downstream direction between RM 132 and RM 120. As a result, the best late-summer rearing for steelhead trout and for Chinook salmon, the best potential spawning areas for sockeye, and best areas for rearing, and foraging habitats for bull trout residing in Lake Billy Chinook occur in the lowermost river segment between the Whychus Creek confluence (RM 123.1) and the lake. It is possible sockeye salmon could use this key reach segment for spawning in the fall. Sockeye fry would return to the lake for rearing. Bull trout are thought to range from Lake Billy Chinook into this segment for foraging opportunities.

2.1.2. Deschutes River – Pelton Re-regulating Dam to the Mouth of the Deschutes River (RM 100 – RM 0.0)

2.1.2.1. Overview

Covered activities in the lower 100 miles of the Deschutes River, designated as Stream Reach 2, consist of five NUID return flows between the Pelton Reregulating Dam and the confluence of Trout Creek (Figure 2-5). This reach is also influenced by all upstream covered activities in the Deschutes and Crooked rivers, and their tributaries.

2.1.2.2. Channel Characteristics

The lower Deschutes River consists of a low-gradient channel with scattered rapids set in a deep, narrow, arid valley. Stream width of the lower river averages 236 feet and varies from 30 to 560 feet, excluding islands (NPCC 2004). The river flows within a constrained channel flanked by deep canyon walls with few side channels. The reach contains a migratory obstruction at Sherars Falls (RM 43), but a ladder was installed at the falls in the 1930s to enhance fish passage. There are a considerable number of east bank and west bank tributaries flowing into the Deschutes River below RM 100, the largest include Shitike Creek, Trout Creek, Warm Springs River, Bakeoven Creek, White River, and Buck Hollow Creek.

2.1.2.3. Flow Characteristics

For assessment purposes, the DBHCP will use river flows for this reach as recorded at the Deschutes River gage at Madras (USGS # 14092500). This gage picks up inflow from the Crooked and Metolius River basins as well as tributary inflow into Lake Simtustus, including Willow Creek. The gage does not include tributary inflow to the Deschutes River downstream of RM 100, making the evaluation of DBHCP activities in this reach a conservative assessment.

Streamflow in this reach is relatively uniform throughout the year due to a high contribution of spring fed waters from upstream springs. High flow events and associated bedload redistribution occur infrequently (Hosman et al. 2003). This stable flow pattern supports healthy riparian communities. Alder, willow, birch and some cottonwood trees dominate the riparian vegetation with shrubs, grasses, sedges, rushes, and other forbs along the water's edge.

This reach experiences only small seasonal variations in discharge because of large groundwater contributions from the upper Deschutes River, Metolius River and lower Crooked River (Gannett et al. 2002). Groundwater contributions within the reach boost flow further; the river gains 400 cfs from groundwater inflow between Round Butte Dam and Dry Creek at RM 91.8 (Gannett et al. 2001). Monthly flow exceedance curves for the Madras gage are shown in Figure 2-6.

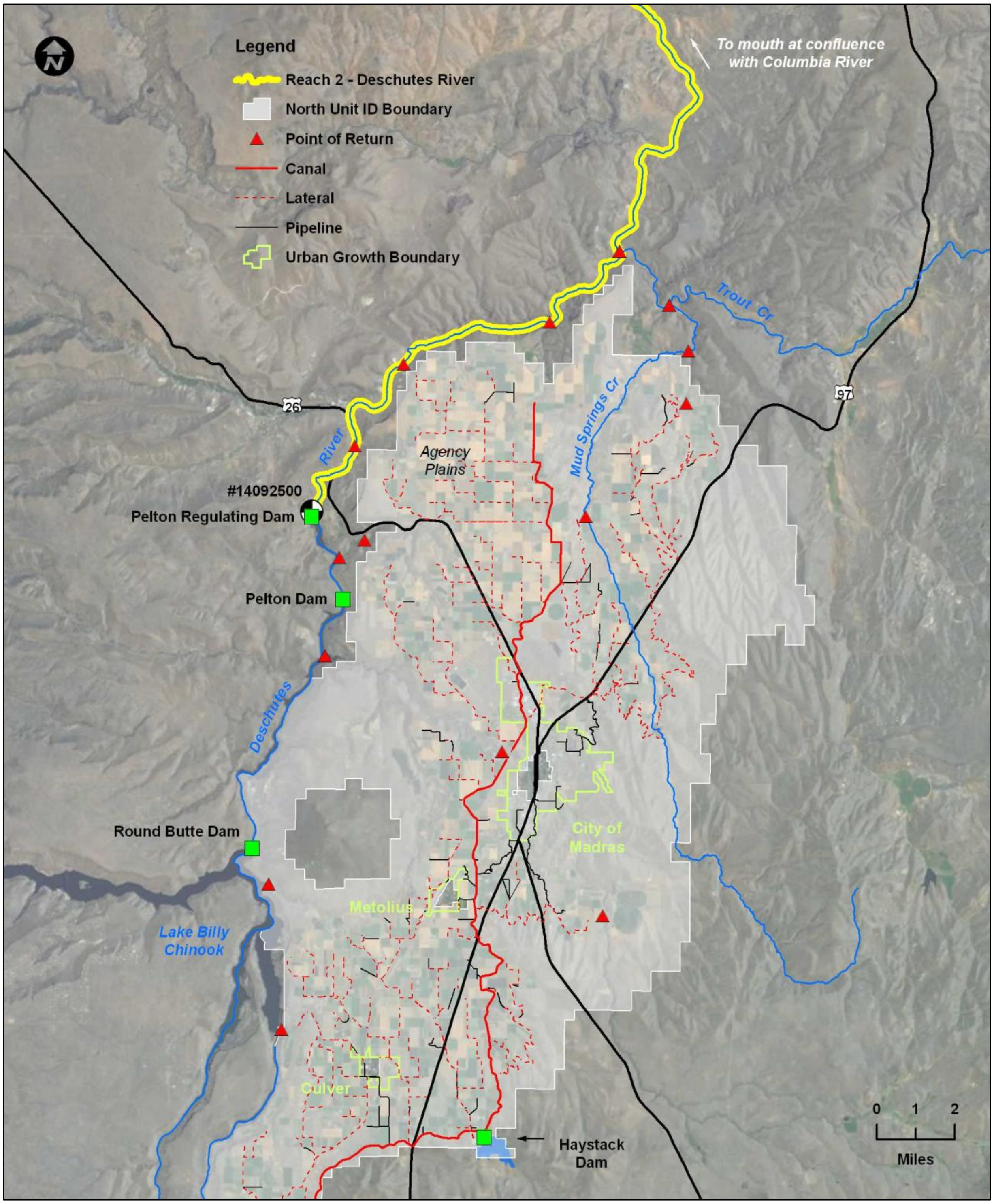


Figure 2-5. Map of Stream Reach 2 of the Deschutes River between Pelton Reregulating Dam and Trout Creek.

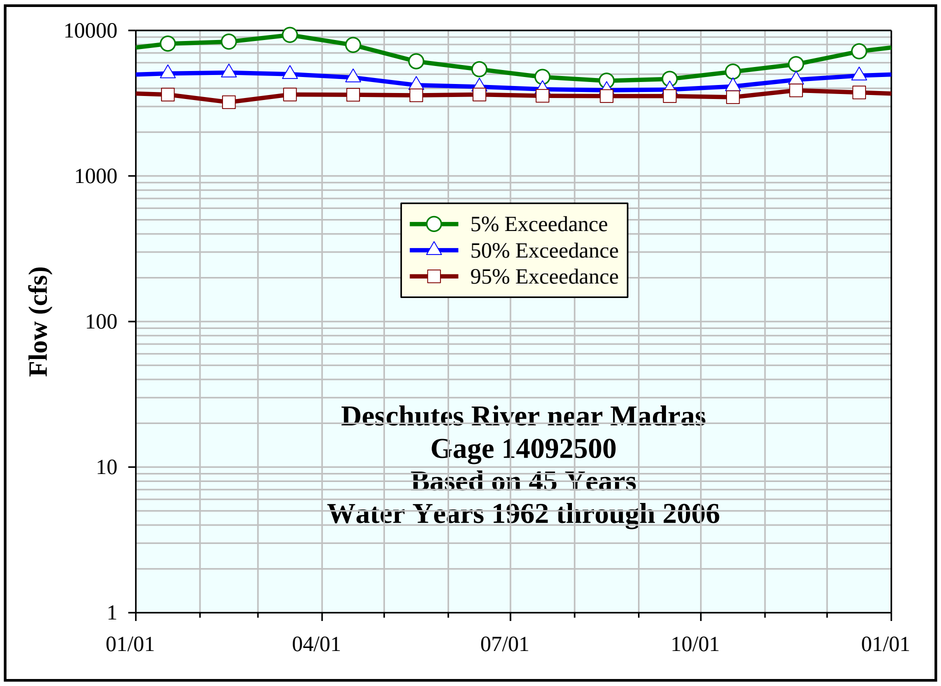


Figure 2-6. Monthly flow duration curves for the Deschutes River near Madras gage # 14092500.
Source: USGS/OWRD data

Water quality and temperature immediately downstream of the Pelton Round Butte Project are driven by the operation of the hydro project (Huntington et al. 1999). The new Selective Water Withdrawal (SWW) facility blends warm surface waters and cool reservoir bottom waters to match the potential natural thermal variation in accordance with the CWA §401 Water Quality Certification for the project (ODEQ 2002).

2.1.2.4. Fish Habitat

The reach provides important spawning and rearing habitat for salmonid fishes. Salmonids also use the reach as they move to and from tributary spawning and rearing grounds. Aquatic habitat including large boulders, bedrock irregularities, rooted aquatic macrophytes, overhanging vegetation, and varying water turbulence and depth provides diverse refuge for covered fish species. The stream and island margins provide important rearing habitat and escape cover for juvenile fishes. Most steelhead spawning from the Reregulating Dam to the mouth of Trout Creek occurs in side channels between islands and channel margins, despite the low frequency of this habitat type within the reach (Zimmerman and Ratliff 2003; Zimmerman and Reeves 2000). Large boulders and cobble also provide good instream structure. Wood from riparian areas, mainly white alders, accumulates between high flows and enhances instream habitat (NPCC 2004).

The substrate of the lower 50 miles of the Deschutes River contains high levels of glacial sand and silt that is carried from Mt Hood via the White River. The lower river also receives heavy silt loads from other tributaries during high-intensity storms. As a result, lower mainstem spawning areas often contain high amounts of fines and are frequently embedded (Huntington 1985).

2.1.2.5. Key Reach Segments

The 12.8-mile segment between the Pelton Reregulating Dam (RM 100) and the confluence of Trout Creek (RM 87.2) is the key segment in this reach for the DBHCP since it is located upstream of all tributary influences. As a result, upstream covered activities have a greater overall influence on this segment than on any other segment of the river downstream of the Pelton Round Butte Project.

Additionally, water temperatures in the river segment immediately downstream of the Pelton Reregulating dam are the coolest in the 100-mile reach and offer the best habitat for year-round rearing of steelhead and bull trout and for Chinook salmon. Sockeye juveniles and adults use this section for upstream and downstream migration.

2.1.3. Whychus Creek – Plainview Ditch to the Mouth of Whychus Creek (RM 25.8 – RM 0.0)

2.1.3.1. Overview

The Whychus Creek drainage covers approximately 230 square miles. The creek enters the Deschutes River at RM 123.1, a few miles above Lake Billy Chinook (Figure 2-7). Covered activities in Whychus Creek include the diversion of water at the Three Sisters Irrigation District's (TSID's) Whychus Creek diversion (RM 24.2) and at a single TSID patron pump between the Whychus Creek diversion and the Plainview Ditch (RM 25.8).

Whychus Creek drains the forested eastern slopes of the Cascade Range, drops into sagebrush steppe and farm and ranch lands in the lower watershed, and passes through the City of Sisters before reaching the Deschutes River. Indian Ford Creek enters Whychus Creek near RM 18, just downstream of the City of Sisters. The upper Whychus Creek watershed is federal land administered by the U.S. Forest Service, while the lower watershed (more than half the total) is in private ownership (UDLAC 2003). Riparian conditions along upper Whychus Creek are generally good, though some areas show damage from timber harvest, grazing, water and recreation use. The most severe riparian condition extends from just above the City of Sisters downstream 11 miles near River Rim Ranch. This stream segment has been damaged by past grazing, channel alterations, and development. Many sections of lower Whychus Creek have a broad riparian area comprised of floodplains, willow stands, and cottonwood bottom lands.

2.1.3.2. Channel Characteristics

Following a flood in 1964, the U.S. Army Corps of Engineers channelized 18 miles of Whychus Creek, near and downstream of the City of Sisters. Approximately two miles of high quality spawning and rearing habitat was lost when the creek was altered from its naturally meandering path through the Camp Polk meadow to a straightened and deepened channel along the margins of the canyon. Recent restoration by the Deschutes Basin Land Trust and the Upper Deschutes Watershed Council has returned the creek in this area back to a meandering channel (Figure 2-8).

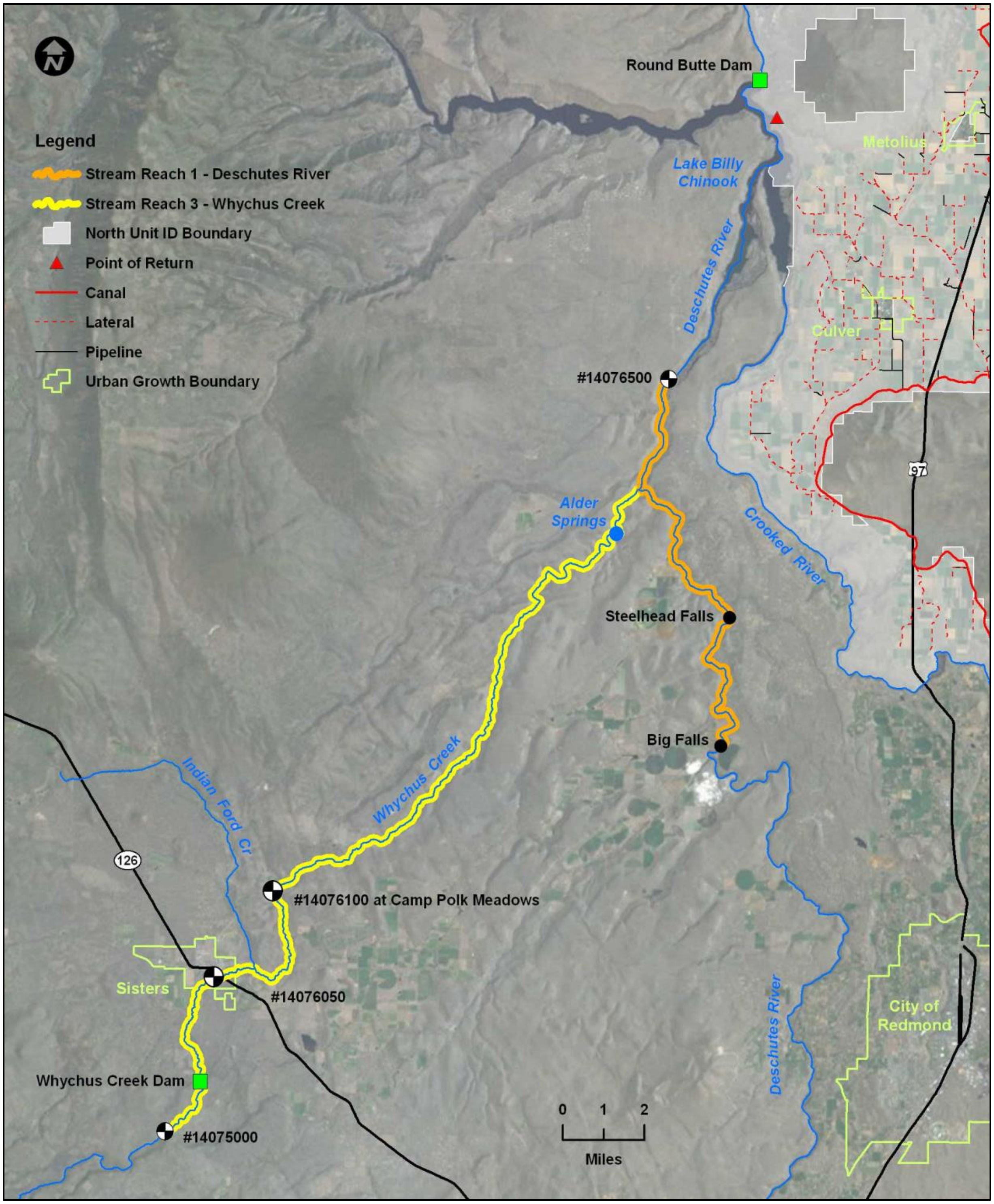


Figure 2-7. Map of Stream Reach 3 from the Plainview Ditch to the mouth of Whychus Creek.

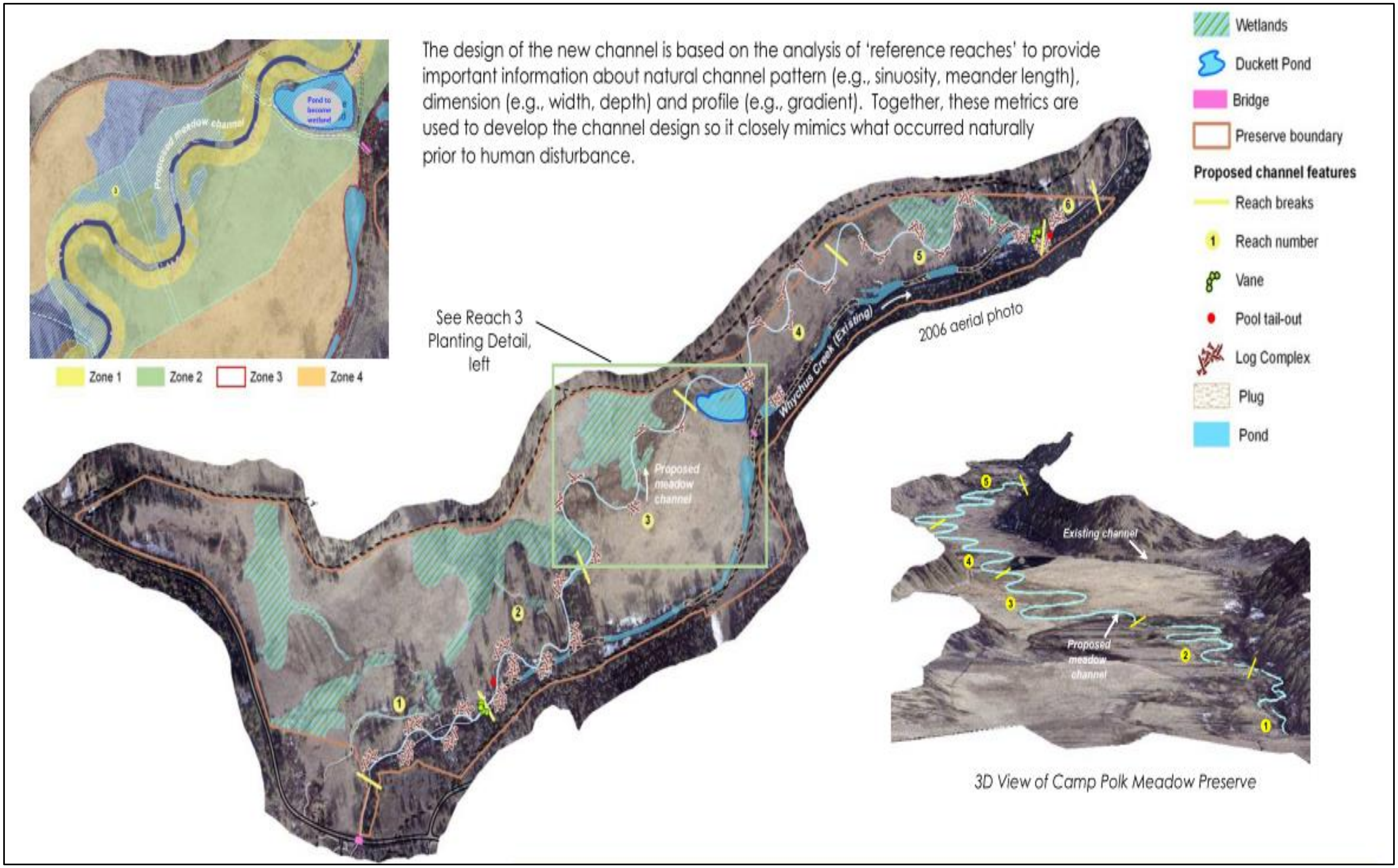


Figure 2-8. Whychus Creek Restoration Project, Camp Polk Meadow Preserve.
Source: UDWC (2007)

2.1.3.3. Flow Characteristics

Streamflows in Whychus Creek fluctuate widely from season to season. Flow typically peaks during the height of snowmelt, usually in May and June, and then reaches a minimum in late fall and winter. Heavy rain-on-snow events can increase flow in the creek by a factor of 20 in a single day (UDLAC 2009). During the summer, a series of irrigation diversions remove most of the water from the creek below RM 24. At times, portions of the stream have been known to run subterranean, primarily due to irrigation diversions. Flows gradually increase again between the City of Sisters (RM 20) and Camp Polk Road (RM 16) with the discharge from a series of springs and irrigation return flows. Springs near Camp Polk Road contribute approximately 7 cfs to the creek. Indian Ford Creek, which joins Whychus Creek at RM 18, becomes dry due to irrigation diversions, but water lost in this tributary may later resurface as springs (NPCC 2005). Alder Springs (RM 1.6) contributes nearly 75 cfs, and Whychus Creek eventually delivers a minimum of nearly 100 cfs to the Deschutes River due to the combined effects of groundwater springs (UDLAC 2003). With the work of the Upper Deschutes Watershed Council, Deschutes River Conservancy, and the Three Sisters Irrigation District, current flows can be expected to be in excess of 15 cfs during the summer months through a segment that frequently was dry in the past due to irrigation diversions.

For assessment purposes, the DBHCP will use stream flows for this reach as recorded at the Whychus Creek gage near Sisters (USGS # 14075000) and Whychus Creek gage at Sisters (#14076050). The gage near Sisters is upstream of the Three Sisters Irrigation District diversion and prior to inflow from Indian Ford Creek and the Camp Polk and Alder Springs. Monthly flow exceedance curves for the Whychus Creek near Sisters gage are shown in Figure 2-9. The gage at Sisters is located downstream of the Three Sisters Irrigation District point of diversion.

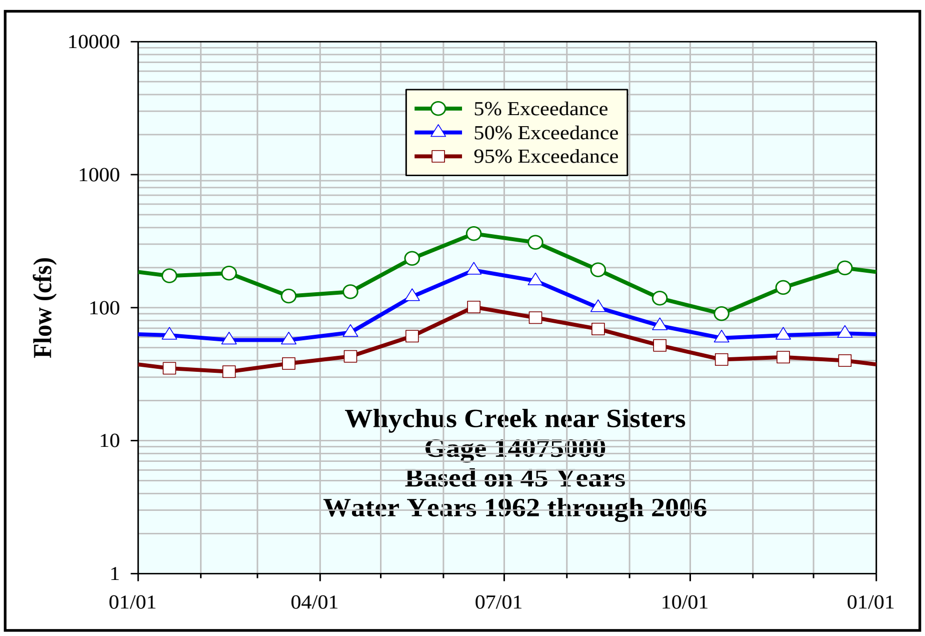


Figure 2-9. Monthly flow duration curves for Whychus Creek near Sisters gage #14075000.
Source: USGS/OWRD data

2.1.3.4. Fish Habitat

The entire 26-mile reach provides important habitat for reintroduced salmon and steelhead trout now that passage has been restored at the Pelton Round Butte Project. Prior channel alterations and streambank erosion have reduced habitat quality. In particular, channel simplification has reduced channel complexity and stability from RM 24.7 to RM 5, resulting in a loss of sinuosity and stream length. Lower Whychus Creek also displays a high percentage of fine sediment associated with unstable streambanks and livestock grazing. Large wood volume is low or absent from the channel in this reach. Some irrigation diversions from Whychus Creek lack screens and fish passage facilities.

High water temperatures particularly limit fish production in the portions of Whychus Creek where flows are reduced by irrigation diversions. Summer water temperatures rise to over 21°C (70°F) downstream of diversions near the City of Sisters. The warm water temperatures often result in low dissolved oxygen levels. Water quality and fish habitat in Whychus Creek are also reduced by high turbidity, high nutrient levels, streambank erosion, decreased stream flow, and a general lack of stream structure. Stream channel and flow restoration are underway as described above to aid with the reintroduction of anadromous fish.

Using HabRate methods for qualifying life history stage habitat conditions to produce spring Chinook salmon in accordance with ODFW protocols (Burke et al. 2003, 2010), Spateholts (2012) indicated this reach is fair for egg to fry survival, fair to poor for fry to parr survival, and good for parr to smolt survival, with an estimated Unit Characteristic Method (UCM) smolt capacity of 18,103 outmigrating spring Chinook smolts. Similarly, following the work of Ackerman et al. (2007), Spateholts (2012) used the UCM to estimate the summer steelhead parr production capacities. Whychus Creek was estimated to produce 32,703 summer parr, all of which were predicted to be of the anadromous life history form. Assuming a 50 percent parr to smolt survival rate, this estimate predicts an outmigrating smolt capacity of 16,350 steelhead smolts, or approximately 370 smolts per accessible stream mile.

2.1.3.5. Key Reach Segments

There are at least four distinct channel segments within the 26 mile section of interest in Whychus Creek:

- Forested channel segment between the TSID facilities and the City of Sisters,
- Urban channel segment within and near the City of Sisters,
- Canyon channel segment downstream of Sisters,
- Groundwater influenced channel segment downstream of Alder Springs (RM 1.6)

Each of these areas should be regarded as a separate response segment from an instream flow perspective since changes in stream flows could have different results with respect to habitat changes in each segment.

The 1.6-mile section of Whychus Creek between its confluence with the Deschutes River and Alder Springs (RM 0.0–1.6) is a key segment for the DBHCP because it offers the most flow and coolest water temperature regimes in the lowermost 26-mile reach accessible to anadromous fishes. This stream segment is comprised of the best habitat for spawning of all four covered fish species and for year-round rearing of juvenile steelhead trout and Chinook salmon. Sockeye salmon did not historically use Whychus Creek. If they were to move upstream from Lake Billy Chinook to opportunistically spawn in the creek, the fry would return to the lake for rearing. Bull trout are thought to range from Lake Billy Chinook into lower Whychus Creek for foraging opportunities, but may find suitable water temperatures for spawning and rearing in this segment, as well.

Another key segment of Whychus Creek lies in the vicinity of Camp Polk meadow preserve, between RM 16.0 and RM 17.5, where springs provide an infusion of cool groundwater and recent restoration efforts have returned the channel to a meandering channel morphology (Figure 2-5). Peak summer temperatures in this segment of Whychus Creek are appropriate for juvenile steelhead trout and juvenile spring Chinook salmon (Watershed Sciences and MaxDepth Aquatics 2008). The restored channel gradient and meander pattern should also offer quality spawning opportunities for steelhead and Chinook.

The forested channel segment between the TSID dam and Sisters (RM 24.1 and RM 20) will likely experience the largest changes in habitat characteristics related to flow scenarios because it is closer to the dam and has less total additional inflow than reaches further downstream. This segment will be key to evaluating the effects of covered activities.

2.1.4. Crooked River– Bowman Dam to the Crooked River Diversion (RM 70.5 – RM 57.0)

2.1.4.1. Overview

The lower portion of the Crooked River flows approximately 70 miles from Bowman Dam through Lake Billy Chinook to the Round Butte Dam. The uppermost 13.5 mile portion of this segment, designated as Stream Reach 4, lies within an upper canyon between the dam and Crooked River Diversion (Figure 2-10).

The Crooked River Project, including Bowman Dam and Prineville Reservoir, was constructed by Reclamation in 1961. The Project is operated by Ochoco Irrigation District (OID). Storage and release of irrigation water at the dam are covered activities that alter flow patterns and potentially influence fish production in this reach. Bowman Dam is also operated for flood control, but this action is not a covered activity in the DBHCP.

2.1.4.2. Channel Characteristics

The Crooked River below Bowman Dam is tightly constrained by low, but steep hills. Although the river channel in this reach consists of very low gradients (0.2% – 0.3%), it is constrained within the canyon walls and can be classified as a large-contained channel. Channel conditions are stable, though spawning habitat is limited. The coarse substrate in this reach provides instream habitat complexity. Riparian and instream habitat conditions remain fair to good throughout the reach; however, tailrace releases from the dam may limit riparian vegetation growth in a portion of the reach. The regulated flows below Bowman Dam are somewhat opposite of natural flows, which were typically high in late winter and low in summer and early fall. Water is now stored in winter and spring, and released for downstream diversion throughout the irrigation season. High flows during the growing season may reduce the area available for riparian vegetation along this confined channel (NPCC 2004).

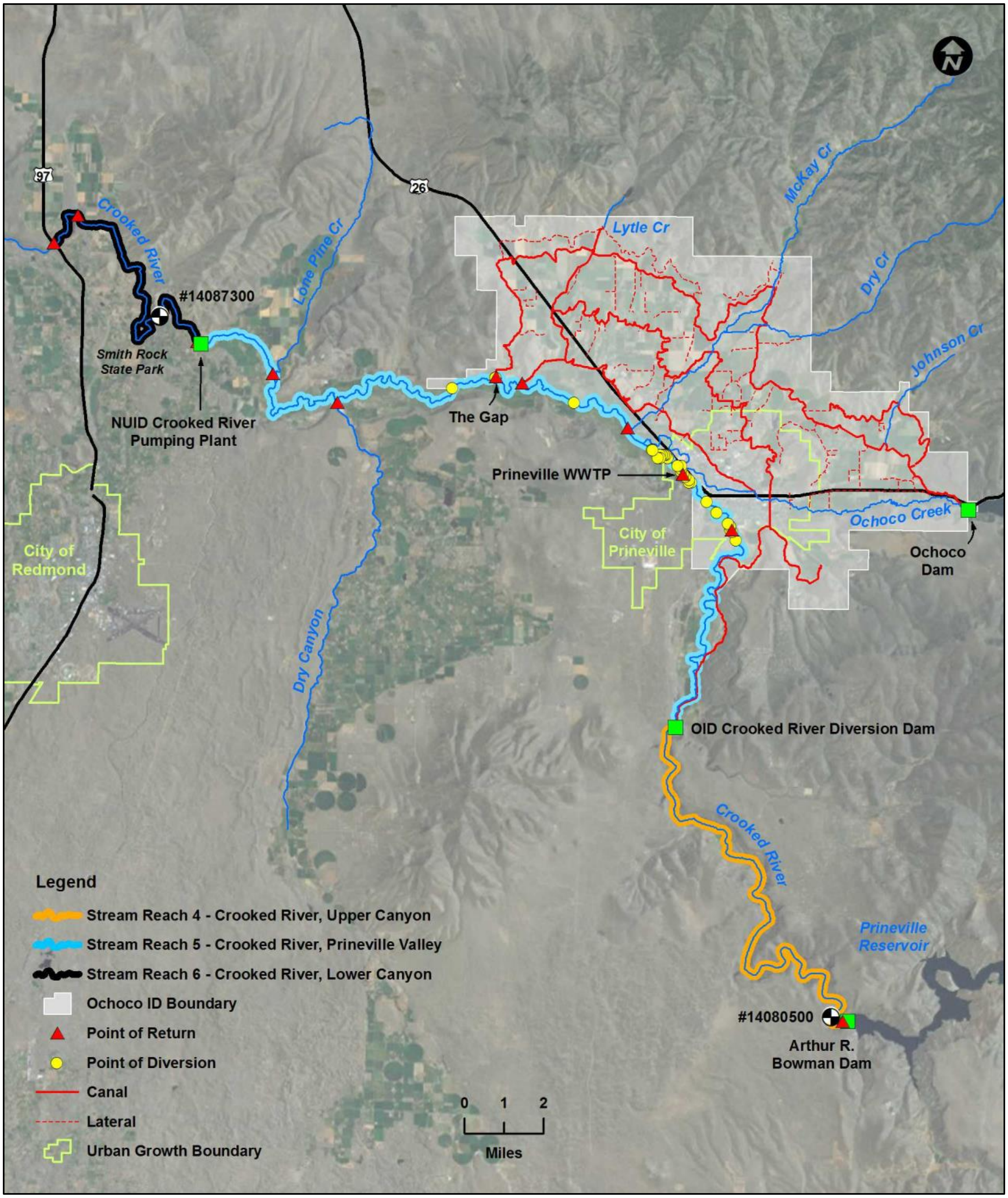


Figure 2-10. Map of Stream Reach 4 of the Crooked River from Bowman Dam to the Crooked River Diversion.

2.1.4.3. Flow Characteristics

River flows recorded at the Crooked River gage near Prineville (USGS # 14080500) will be used for DBHCP assessment purposes. This gage records the outflow from Bowman Dam prior to any covered diversions.

Operations at Bowman Dam have changed the magnitude and timing of peak flows in the lower Crooked River. Before dam construction and operation, 66 percent of the average flow of the Crooked River occurred in the months of March, April, and May. Today, flows are typically 200-250 cfs during the summer irrigation season and 30-75 cfs during the winter storage season. Before the construction of Bowman Dam in 1961, average peak discharges typically ranged from 3,000-7,000 cfs (Whitman 2002). Since construction of the reservoir, flows have ranged from as low as 10 cfs during winter months, the minimum flow required by the project, to as high as 3,000 cfs (Whitman 2002). The goal of flood control operations at the dam is to limit the outflow from the reservoir so as not to exceed 3,000 cfs.

Monthly flow exceedance curves at the Prineville gage for the period of record following Bowman Dam construction are shown in Figure 2-11.

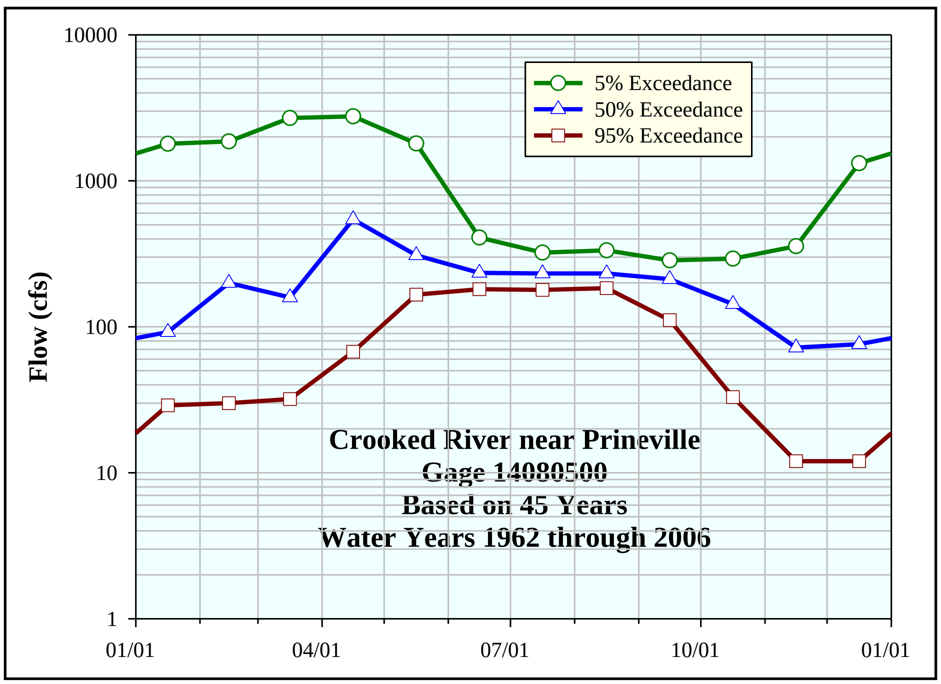


Figure 2-11. Monthly flow duration curves for the Crooked River near Prineville Gage # 14080500.
Source: USGS/OWRD data

Channel conditions in the upper reach remain stable, though flow regulations limit the ability of the stream channel to rejuvenate through landform developing processes such as large floods. Peak flows that used to occur every 2.5 years (about 4,000 cfs) now occur about every 50 years on average. This modification has had an effect on channel morphology (Fies et al. 1996; McSwain 1999; Whitman 2002).

2.1.4.4. Fish Habitat

This reach of the Crooked River contains limited spawning habitat. Cold-water reservoir releases since the 1960s have decreased the ambient water temperatures in the Crooked River below Bowman Dam. Summer water temperatures typically average between 8.3°C (47°F) and 10.0°C (50°F) annually, with a high of 12.4°C (54°F). Winter temperatures average between 2.8°C (37°F) and 4.4°C (40°F) annually, with an absolute recorded low of 0.0°C (32°F) (NPCC 2004). The cold-water releases substantially improve summer water quality and fish habitat in this reach (Stuart et al. 1996), and have created a "tailrace redband trout fishery" that did not exist under pre-dam conditions.

Sediments suspended in the reservoir from the upper watershed create turbid flow in the Crooked River downstream from the dam. Water in the Crooked River is generally turbid throughout the lower basin downstream to RM 16, where sufficient spring inflow contributes to good water clarity and cooler temperatures (Stuart et al. 1996). As discussed in Study 15, this reach of the Crooked River is included on the state 303(d) list for exceeding the total dissolved gas criterion.

Spateholts (2008) used HabRate methods generated by Burke et al. (2003) for qualifying life history stage habitat conditions to produce spring Chinook salmon. The assessment indicated this reach is fair to poor for egg to fry survival, poor for fry to parr survival, and fair for parr to smolt survival, with an estimated smolt capacity of 1,477 smolts per mile or 19,940 outmigrating spring Chinook smolts (Spateholts 2008).

Similarly, following the work of Ackerman et al. (2007), Spateholts (2012) used UCM to estimate the summer steelhead parr production capacities. This reach was estimated to produce 74,920 summer parr, all of which were predicted to be of the resident life history form. Based on the stable river flows and relative cool water temperatures, this reach has been delineated as primarily producing resident redband trout (Zimmerman and Reeves 2000; Ackerman et al. 2007; Spateholts 2008, Courter 2011). These authors suggest flow regimes that provide cool temperatures and maintain depth and velocities necessary to sustain adult redband trout throughout the summer and fall seasons will result in increased resident trout populations and decreased steelhead trout abundance.

Courter (2011) estimated the reach downstream of Bowman Dam could support between 15 and 80 adult steelhead spawners, depending on flow conditions. Juvenile steelhead productivity for the reach could range between 11 and 12 smolts per spawner. Based on competition with other species, this estimate is less than half the juvenile steelhead production anticipated for the downstream Prineville Valley reach during a wet year. Based on habitat-flow relationship patterns, IFIM study results (1993, 2001) suggest higher flows than currently exist may enhance fish production in this reach.

2.1.4.5. Key Reach Segments

The only covered activities influencing the Crooked River between RM 70.5 and RM 57.0 are the storage and release of water from Prineville Reservoir. There are no diversions of water in this reach, so river flow levels are relatively unchanged between Bowman Dam and the Crooked River Diversion. Although juvenile steelhead trout and spring Chinook salmon fry are released annually in this reach segment as part of the reintroduction plan, the primary management strategy for fish species in this reach focuses on resident redband trout. As such, there are no key segments for spawning summer steelhead trout or spring Chinook salmon. Bull trout and sockeye salmon are not anticipated to use the reach between Bowman Dam and the Crooked River Diversion. Following implementation of fish passage facilities at Opal Spring dam, it is possible bull trout could restore their historic foraging distribution in the Crooked River upstream near the City of Prineville (Ratliff et al. 1996). Sockeye salmon did not use the Crooked River historically. Should sockeye spawning occur in the future, they would also likely be limited to areas downstream of RM 18 where they have good access to Lake Billy Chinook for subsequent juvenile rearing.

2.1.5. Crooked River – Prineville Valley Reach; Crooked River Diversion to NUID Pumps (RM 57.0 – RM 27.6)

2.1.5.1. Overview

Covered activities in this reach of the Crooked River, designated as Reach 5, include diversion of water at the Crooked River Diversion and individual OID patron pumps; releases and returns of OID and COID irrigation water; and the City of Prineville activities consisting of surface and groundwater withdrawals, surface water runoff, and wastewater treatment plant discharge (Figure 2-12). Flows in this reach are also influenced by storage and release of irrigation water at Bowman Dam. There are a number of east bank tributaries flowing into the Crooked River in this reach. The largest tributaries include Ochoco, McKay, Lytle, Japanese, and Lone Pine creeks.

2.1.5.2. Channel Characteristics

The Prineville Valley reach of the Crooked River meanders through a wide floodplain with little confinement by geological formations. The river valley channel in this reach consists of very low gradients (0.1% – 0.2%) and is categorized as palustrine. The stream channel has been altered or simplified at several locations throughout the reach and is isolated from the floodplain in some areas. According to the NRCS (2010), the hydrologic response of the Crooked River in this reach has been altered through the construction of flood control reservoirs. This change in hydrology, coupled with land use changes, has altered the natural fluvial geomorphology of the Crooked River through most of the reach (NRCS 2010). Stream straightening occurred in the Crooked River watershed over the last century. At least ten significant meanders existing prior to 1943 were cut off by 2000 (NRCS 2010). Stream banks throughout this reach have been armored with riprap.

Most land adjacent to the river in this section is privately owned. Land use and water utilization on private lands through the valley are for livestock grazing and irrigation for crop production. The reach also includes the City of Prineville urban growth boundary, where lands support residential, industrial and commercial uses.

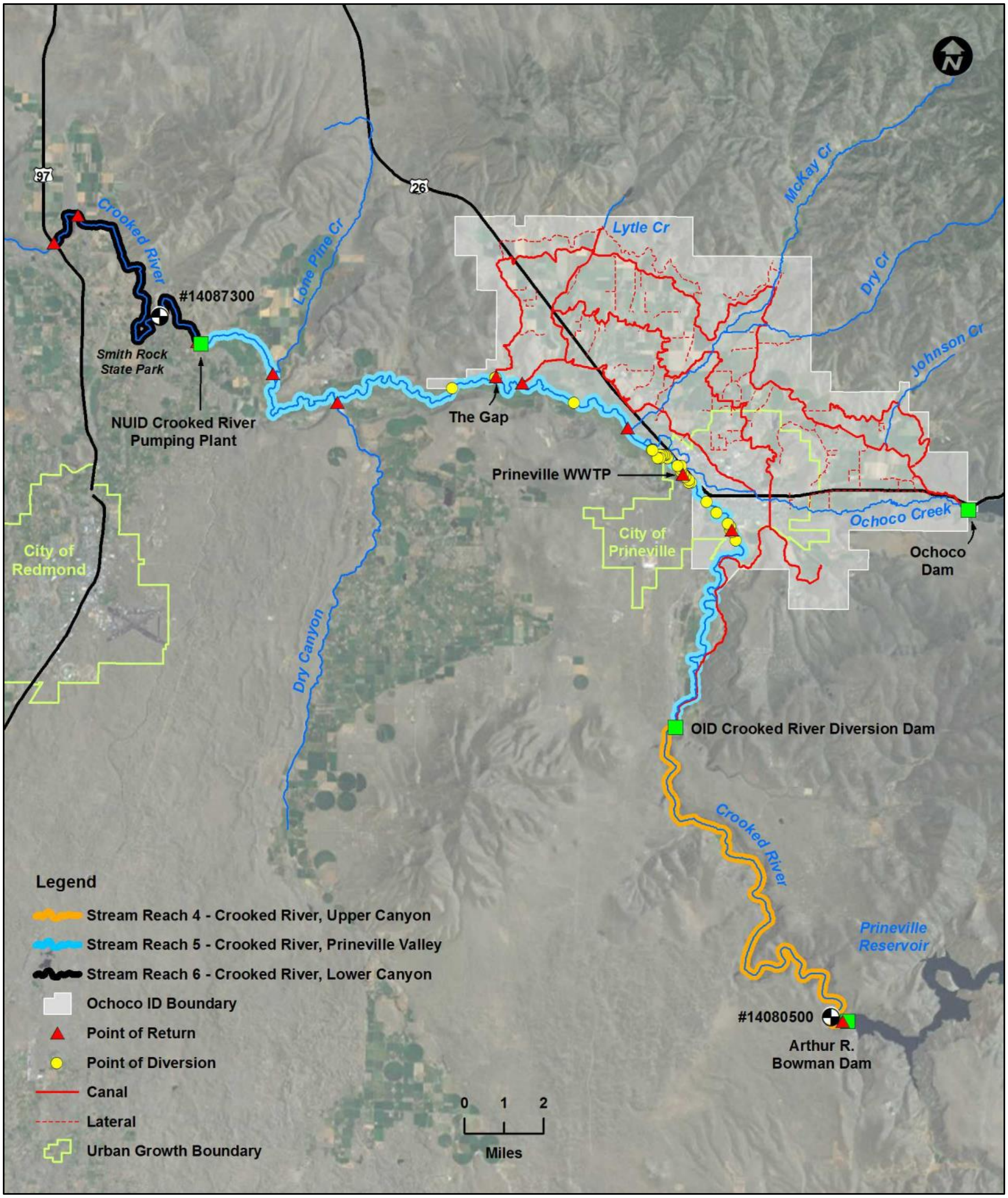


Figure 2-12. Map of Stream Reach 5 of the Crooked River from the Crooked River Diversion to NUID pumps.

Average width of the active channel measured by ODFW in 2005 was 45 feet (ODFW 2006). The stream gradient averaged 0.1 percent. Streambank stability was rated poor since the channel was heavily eroded and vegetation cover was narrow and disturbed. Instream wood material during the ODFW survey was lacking to absent. Pools through this section averaged 2.8 feet in residual pool depth. Habitat areas and streambed substrate composition between Lone Pine Bridge (RM 30) and Peoples Diversion (RM 50) were recorded by ODFW in 2006 (Table 2-2).

Table 2-2. Habitat and substrate composition in the Crooked River reach between Lone Pine Bridge and Peoples Diversion.

Habitat Area	Percent (%)
Pool	65
Riffle	13
Glide	9
Other	13
Substrate Composition	**Percent (%)**
Bedrock	-
Boulder	1
Cobble	19
Gravel	47
Sand and silt	33

Source: AIP data (ODFW 2006)

2.1.5.3. Flow Characteristics

Summer flows in the Crooked River decrease at RM 57, where 160 to 180 cfs are diverted during the irrigation season. Several other diversions remove additional flow below RM 57. Together, these diversions remove most of the remaining water and leave the Crooked River below Prineville with low river flows annually from April to October. River discharges range from 10 cfs, the minimum release required at Bowman Dam, to 3,100 cfs, the USACE safe channel capacity for the river. Irrigation return water, tributary inflows, and groundwater seepage augment stream flow in the lower portions of this reach, though additional irrigators downstream continue to divert water. The combined effect of inflows and additional diversions is a net increase of 60 to 100 cfs through the lower 18 miles of this reach depending on the season (LaMarche 2007; Main 2012).

2.1.5.4. Fish Habitat

This reach of the Crooked River lacks instream habitat complexity. Soils in the reach are naturally susceptible to erosion, and the substrate contains a high percentage of fine sediment. Most artificial migration barriers in this reach have been improved to allow fish passage and habitat connectivity. Some irrigation diversions lack fish screens (Marx 2003).

Summer water temperatures increase in the Crooked River as flow is diverted for irrigation and, as reported by Nielsen-Pincus (2008), water temperatures near Prineville can exceed 25°C (77°F). The reach also suffers from high pH (summer and winter), high bacteria (summer), high biochemical oxygen demand (BOD), and low dissolved oxygen. The Crooked River below RM 51 exceeds Oregon State water quality criteria for summer temperatures, bacteria, and pH. This section is included on the state 303(d) list for water quality-limited waters (ODEQ 2002).

The only major classified NPDES permit for the mainstem Crooked River in this reach belongs to the City of Prineville for their sewage treatment facility at RM 47. The City is only allowed to discharge during the winter months. The quality and amount of the discharge are determined by flow in the Crooked River. If flows are less than 15 cfs, no discharge is allowed. During the summer months, the treated sewage is applied to the golf course in Prineville.

Riparian vegetation has been reduced along most of this reach, and the limited distribution of spawning gravel is of marginal quality. Poor riparian condition has been identified as a reason for reduced fish production in the reach (Stuart et al. 1996).

There are other natural and human-induced factors contributing to generally poor instream habitat conditions for fish in this reach. The shallow channel gradient, naturally erosive soils, and high sediment loads create an area of extensive sediment deposition. Channel alterations and lost riparian vegetation contribute to active bank erosion, compounding the sediment issues. Key habitats for spawning and incubation, fry colonization, and adult holding have been reduced due to decreased instream flows, loss of habitat structure, and poor water quality. Based on habitat-flow relationship patterns, IFIM study results suggest higher river flows than currently exist may improve production of steelhead trout and spring Chinook salmon in this river section (Stuart et al. 1996; Hardin 2001).

2.1.5.5. Key Reach Segments

The Crooked River between OID's diversion at RM 57 and the Highway 26 Bridge in Prineville at RM 48 is considered a key reach segment in the Prineville Valley reach. The stream gradients in this portion of the valley reach are slightly higher than the balance of the reach, making spawning and rearing habitat conditions more suitable for the production of covered fish species. In addition, this segment is likely one with the lowest available river flows due to irrigation diversions. This segment will be key to evaluating the effects of covered activities.

The Crooked River between RM 42.8 and RM 43.2 is also a key segment of the Prineville Valley reach. The channel actively changes the location of its main thread, and high flow relief channels are connected to the mainstem in the segment. This segment is likely a depositional section of the river due to a high width-depth ratio and low hydraulic shear required to maintain sediment transport. This section of the stream benefits from a higher localized water table due to the lateral floodplain connectivity and broad distribution of the active channel (NRCS 2010). The aerial photo in Figure 2-13 shows the presence of several depositional features and vegetation response to the higher water table.

The channel complexity of this section of the Crooked River provides good spawning and rearing habitat for steelhead trout and spring Chinook salmon, with areas of variable depth and velocity. Deep holding pools for resting adults are not present. The vegetation condition is poor due to livestock grazing that leads to increased water temperatures. Hydraulic analysis suggests most of this segment does not meet the minimum ODFW 1.0-ft water depth requirement for fish passage, considering average cross-sectional depths at the 32 cfs level (the 95% exceedance value for the Terrebonne gage). However, maximum depths show adult fish can find at least 1.0 foot of depth somewhere in the flow cross-section over much of this segment (NRCS 2010). The NRCS report implies adult fish will likely pass this segment during extreme low flows, but could be delayed or could expend additional energy finding the appropriate pathway upstream.

Figure 2-13. Crooked River RM 42.8 – RM 43.2 showing changing channel activity due to high localized groundwater table.
Source: NRCS (2010).

In their hydraulic analysis of the Crooked River, the NRCS implied upstream passage might be a concern in the Prineville Valley reach for anadromous salmonid fishes (NRCS 2010). As shown in Table 2-3, ODFW reaches 2 and 3 near Dry River and McAllister Slough (RM 34.1-39.8), reaches 5, 6, 7 between Lytle and Ochoco creeks (RM 41.0-45.5); and reach 10 near the Hwy 126 Bridge (RMs 48.4-50.5) have more than half of the segment lengths with less than a foot of water depth at 32 cfs. Due to their sensitivity to flow, these areas represent key segments with respect to the effects of covered activities.

Table 2-3. Percent of ODFW stream segments in the Prineville Valley Reach that do not meet the Low Fish Passage Design Flows of 0.5 and 1.0-ft maximum water depth at a river discharge of 32 cfs.

Depth	ODFW #1	ODFW #2	ODFW #3	ODFW #4	ODFW #5	ODFW #6	ODFW #7	ODFW #8	ODFW #9	ODFW #10
	RM 30.0-34.1	**RM 34.1-37.4**	**RM 37.4-39.8**	**RM 39.8-41.0**	**RM 41.0-43.9**	**RM 43.9-44.9**	**RM 44.9-45.5**	**RM 45.5-46.8**	**RM 46.8-48.4**	**RM 48.4-50.5**
0.5’	14	24	22	20	29	29	32	13	22	28
1.0’	33	58	62	40	58	62	80	47	47	59

Source: NRCS 2010

Following implementation of fish passage facilities at Opal Spring dam, bull trout may move as far upstream as the City of Prineville when conditions are favorable for foraging (Ratliff et al. 1996). Sockeye salmon are not anticipated to use the Prineville Valley reach of the Crooked River. Sockeye salmon did not use the Crooked River historically. Should sockeye spawning occur in the future they would also likely be limited to areas downstream of RM 18 where they have good access to Lake Billy Chinook for subsequent juvenile rearing.

2.1.6. Crooked River – NUID Pumps to Highway 97 (RM 27.6 – RM 18.0)

2.1.6.1. Overview

Covered activities in this section of the Crooked River, designated as Reach 6, include diversion of water at NUID's Crooked River Pumping Plant, and releases and returns of NUID irrigation water (Figure 2-14). Flows in this reach are also influenced by storage and release of irrigation water at Bowman Dam, and by multiple irrigation diversions between Bowman Dam and the NUID pumps. There are a few tributaries and channel features within the Crooked River in this reach. The largest include Smith Rock State Park, Osborne Canyon, and Ogden State Park.

2.1.6.2. Channel Characteristics

The lower canyon reach of the Crooked River, from RM 27.6 to Highway 97 at RM 18.0, is constrained within high canyon walls (Photo 2). The stream morphology consists of a mixture of boulder-strewn riffles and long glides. An extensive length of this stream segment is higher gradient (1%) than the upstream reaches of the Crooked River, with fast moving whitewater and a boulder-strewn channel.

2.1.6.3. Flow Characteristics

NUID periodically diverts up to 200 cfs of live flow from the Crooked River at RM 27.6 during the irrigation season. A minimum flow of 10 cfs is bypassed below the pumps, but the flow level downstream is often higher. The NRCS performed a statistical regression analysis between the existing USGS gage at Culver and the Terrebonne gage, allowing for a good estimate of flow duration for the discontinued Terrebonne gage. The 95 percent exceedance level at the Terrebonne gage (flow level exceeded 95% of the time) at RM 27 is calculated as 32 cfs (NRCS 2010). In 1993, the Terrebonne gage was relocated slightly downstream to Smith Rocks and operated as OWRD gage CRSO (#14087300). The mean monthly flows are lowest typically during the month of July ranging between 12 and 160 cfs and averaging 81 cfs during the 14 year period of record at the Smith Rocks gage. For assessment purposes, the DBHCP will use stream flows for this reach as recorded at the active Crooked River gage at Smith Rocks (USGS # 14087300).

Sediments suspended in the water column create turbid flow in the Crooked River through the entire reach to near Highway 97, where spring inflow contributes to good water clarity and cooler temperatures (Figure 2-15). These naturally-augmented flows below Highway 97 contribute to stable water flows, cooler water temperatures, and improved water quality. The volume of flow contributed from springs increases as the river flows northward, and averages over 1,550 cfs by the time the river enters Lake Billy Chinook. Groundwater inflows improve water quality and temperature in such a manner that a coldwater fishery is supported in the river downstream from this reach (Fies et al. 1996).

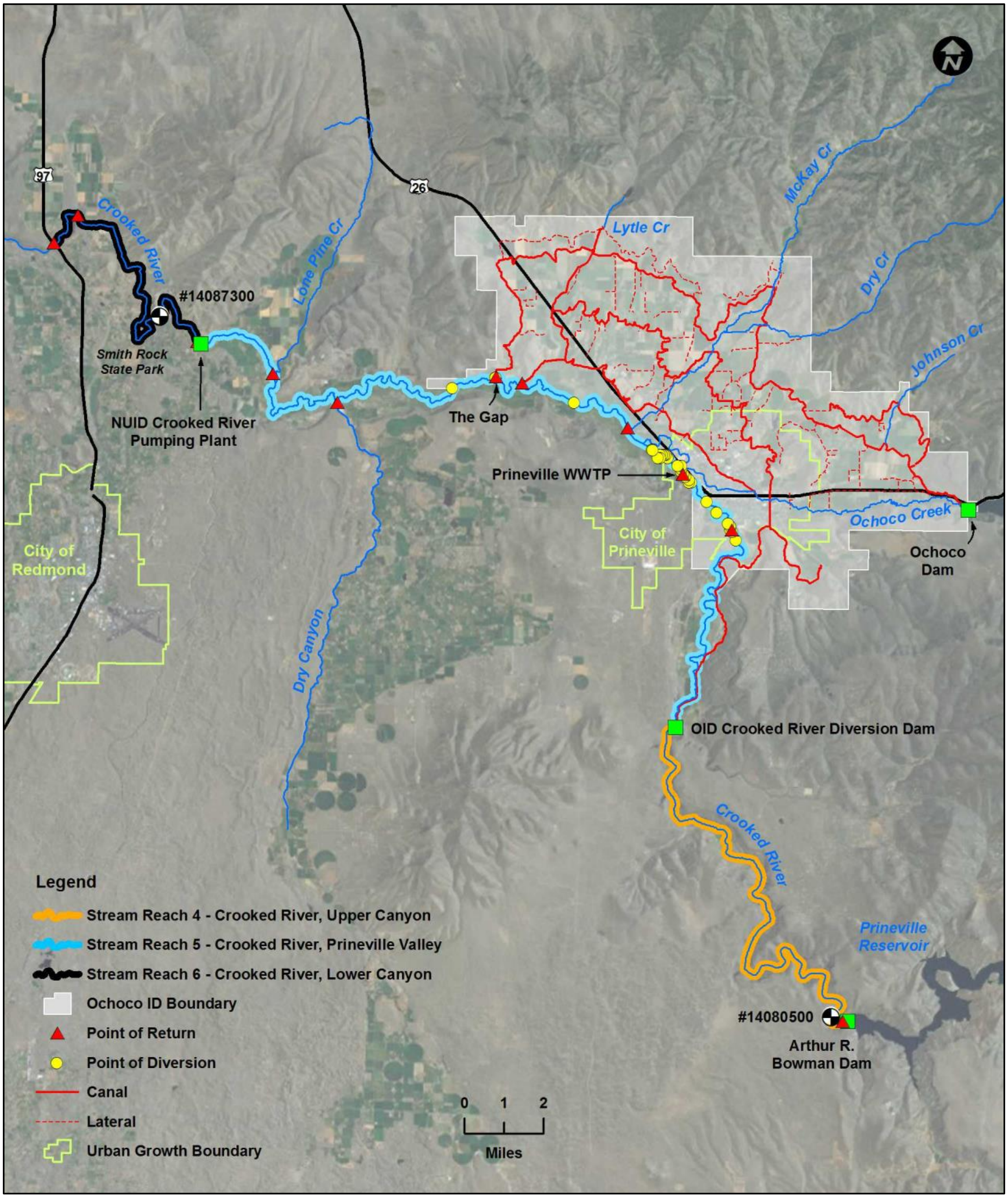


Figure 2-14. Map of Stream Reach 6 of the Crooked River from the Crooked River Diversion to NUID pumps.

Photo 2. Crooked River Canyon.
Source: Gannett et al. (2001).

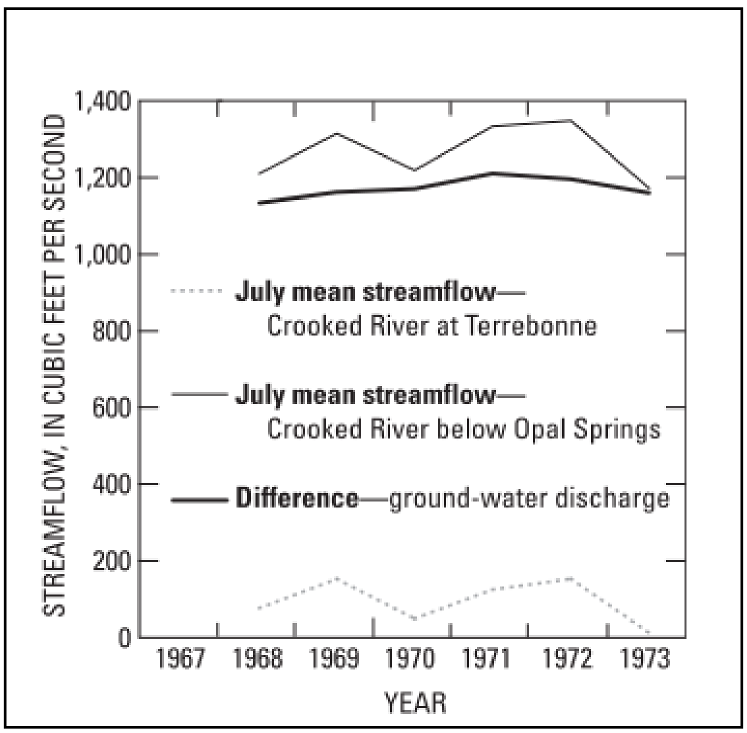


Figure 2-15. July mean flows at Opal Springs and at Terrebonne and the difference between the two gages, 1967 to 1973.
Source: Gannett and Lite (2004).

2.1.6.4. Fish Habitat

The lower canyon reach suffers from high pH (summer and winter), high bacteria (summer), high biochemical oxygen demand (BOD), and low dissolved oxygen. Water quality improves below Highway 97 with additional flow from natural springs (Figure 2-8). The Crooked River in this reach exceeds State water quality criteria for summer temperatures, bacteria and pH, and is listed as a water quality-limited river reach under Clean Water Act Section 303(d) (ODEQ 2002).

Based on habitat-flow relationship patterns, IFIM study results (Hardin 1993, 2001) suggest flows may limit fish production in this reach. Courter (2011) estimate the Lower Canyon reach could support between 30 and 100 adult steelhead spawners, depending on flow conditions. Juvenile steelhead productivity for the reach could range between 12.7 and 14.1 smolts per spawner.

With the application of HabRate methods, Spateholts (2008) indicated this reach is fair to poor for egg-to-fry survival, poor for juvenile summer rearing and survival, and fair for winter survival, with an estimated summer capacity of 1,594 parr. All of these fish were predicted to be of the anadromous life history form (Spateholts 2008). Assuming a 50 percent parr-to-smolt survival rate, this estimate predicts an outmigrating smolt capacity of nearly 800 steelhead smolts, or approximately 83 smolts per stream mile in the Lower Canyon reach. Using the mean of Courter (2011) productivity data, Spateholts' smolt estimates could be generated from approximately 60 steelhead spawners.

Similarly, Spateholts (2008) estimated the spring Chinook juvenile outmigrant production at 108 smolts per mile. This estimate equates to 1,044 spring Chinook salmon smolts for this 9.6 mile reach.

2.1.6.5. Key Reach Segments

Because water temperatures exceed biological criteria for spawning and summer rearing of salmonid fishes throughout this section of the Crooked River, and because the covered activities can influence water temperature, the entire reach is designated as a key reach segment for steelhead trout and spring Chinook salmon.

Following implementation of fish passage facilities at Opal Spring dam, bull trout may move upstream into this reach when conditions are favorable for foraging (Ratliff et al. 1996). Sockeye salmon are not anticipated to use the Lower Canyon reach. Sockeye salmon did not use the Crooked River historically. Should sockeye spawning occur in the future they would also likely be limited to areas downstream of RM 18 where they have good access to Lake Billy Chinook for subsequent juvenile rearing.

2.1.7. Ochoco Creek – Ochoco Dam to the Mouth of Ochoco Creek (RM 10.5 – RM 0.0)

2.1.7.1. Overview

Ochoco Creek joins the Crooked River at RM 45.5. The drainage comprises about 150 miles of stream and drains an area of 360 square miles (230,400 acres). Ochoco Dam, built in 1922, impounds the creek at RM 11.1, forming Ochoco Reservoir. Dam operations and irrigation diversions alter flow patterns in the lower 11.1 miles of Ochoco Creek, designated as Stream Reach 7 (Figure 2-16).

2.1.7.2. Channel Characteristics

Habitat complexity has been reduced along lower Ochoco Creek through stream channelization and land use berming. Several areas are isolated from their floodplains. Assessments conducted on Ochoco Creek in 2000 for the Crooked River Watershed Council indicated channels were highly sensitive to land use activities or channels that are very responsive to changes in flow, sediment, woody debris or other inputs along 84 percent of Ochoco Creek (Walter 2000). Channel habitat types in this reach were described by Nielsen-Pincus (2008) as consisting of mostly broad valleys with terraces, in association with floodplains and alluvial soils. The channel was slightly entrenched with a well-defined meandering channel and a pool-riffle bed morphology, exhibiting lateral instability with high bank-erosion rates.

2.1.7.3. Flow Characteristics

Flows in lower Ochoco Creek respond to water storage and releases. Ochoco Dam operations reverse the natural seasonal flow pattern in the lower stream reach. High flows occur during irrigation (April to mid-October) and low flows occur while water is stored for the next irrigation season. Currently, the state of Oregon annually leases water from existing water rights in the basin to maintain 7 to 10 cfs of instream flow during the summer irrigation season.

Stream flows recorded at the Ochoco Creek gage below Ochoco Reservoir (USGS # 14085300) will be used for DBHCP assessment purposes. This gage records the release of water from the Ochoco Main Canal and seepage collected from the face of Ochoco Dam. Monthly flow exceedance curves at the Ochoco Creek gage are shown in Figure 2-17.

2.1.7.4. Fish Habitat

In their annual report, the Oregon State Game Commission reported a concentration of steelhead in undetermined numbers found in Ochoco Creek near the town of Prineville (OSGC 1956). Similarly, historic journals mention good spring Chinook salmon populations in lower Ochoco creek.

Water releases to this reach from Ochoco Dam (RM 11.1) occur from depth within Ochoco Reservoir and are relatively cool, rarely exceeding 15.0°C. The water temperatures in the creek increase in the downstream direction during summer months (Figure 2-18). A series of diversions, spills, and springs alternately decrease and increase stream flows and water temperatures. Ochoco Creek downstream of RM 8 routinely surpasses State water temperature criteria for salmonid spawning and rearing. The entire reach of Ochoco Creek is on the state's 303(d) list for temperature-impaired water bodies (ODEQ 2002). Other fish habitat limitations as noted by Stuart et al. (1996), NPCC (2004), and Nielsen-Pincus (2008) are related to:

- low winter flows associated with upstream water storage in Ochoco Reservoir
- channel simplification, including bermed and channelized stream reaches
- instream structure that is generally lacking
- a degraded riparian corridor, and
- sedimentation from stream bank erosion that affects stream substrate quality

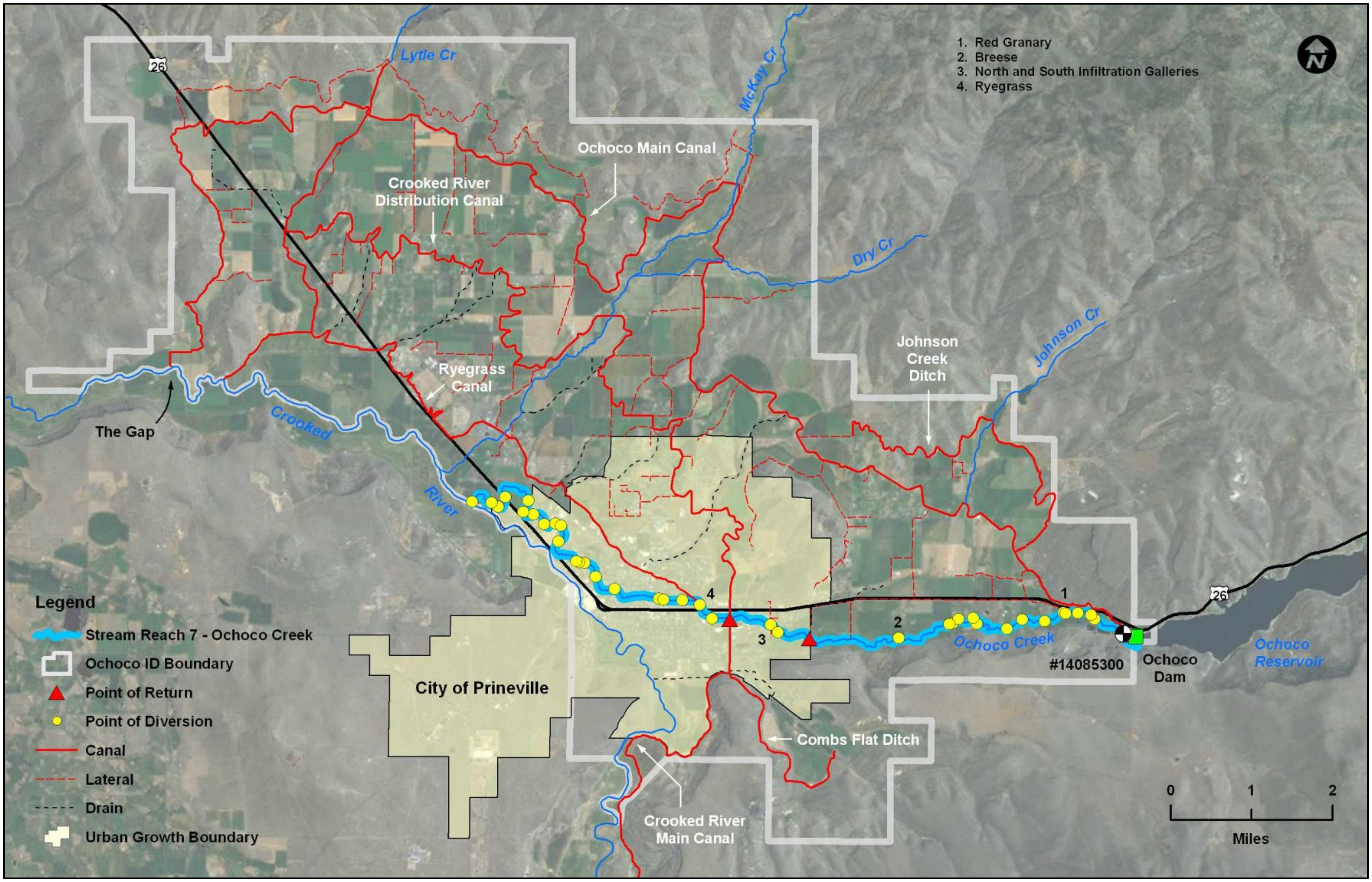


Figure 2-16. Map of Stream Reach 7 from Ochoco Dam to the mouth of Ochoco Creek.

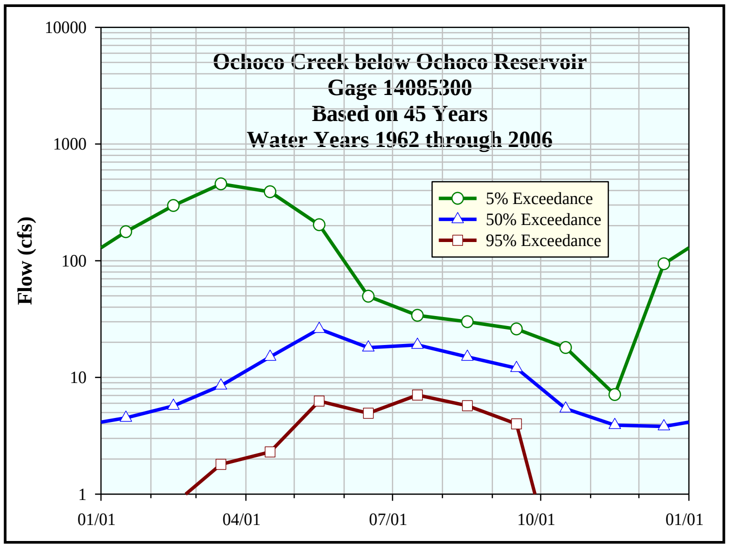


Figure 2-17. Monthly flow duration curves for the Ochoco Creek below Ochoco Reservoir Gage # 14085300

Source: OWRD data

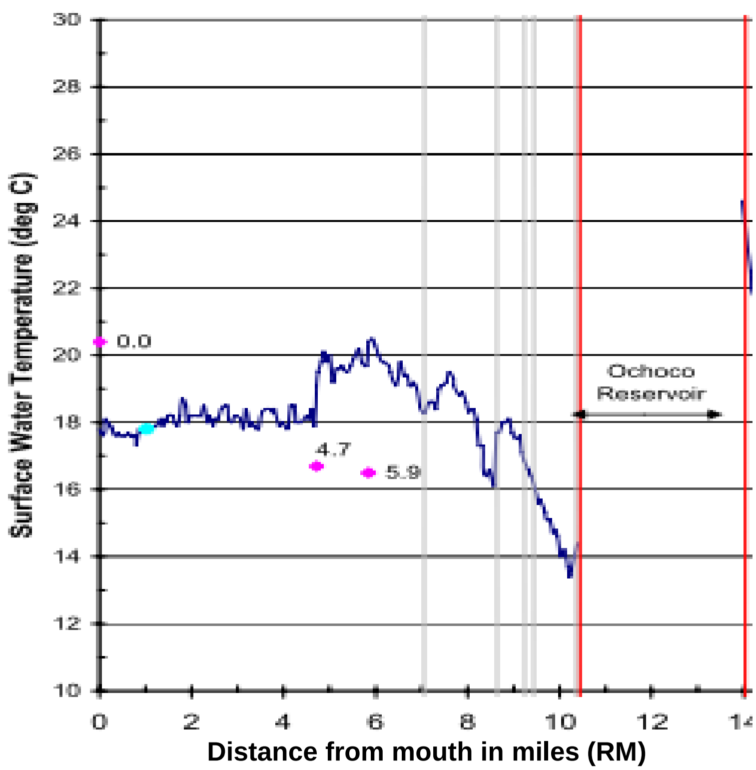


Figure 2-18. Longitudinal water temperature profile for Ochoco Creek from its mouth at the Crooked River to Ochoco Reservoir-July 2005.

[Pink and blue dots represent springs or tributary inputs].

Source: Watershed Sciences 2006

The riparian corridor along lower Ochoco Creek has been damaged by livestock grazing, channel simplification, urban development in the Prineville area, and agricultural practices. Riparian assessments conducted in 2000 using OWEB methodology in Ochoco Creek showed generally inadequate riparian conditions (Whitman 2002).

Spateholts (2012) estimates Ochoco Creek downstream of the dam could support a smolt capacity of 5,067 spring Chinook salmon smolts. The steelhead smolt capacity for this reach equates to 4,507 outmigrants (Spateholts 2012).

2.1.7.5. Key Reach Segments

Two reach segments of Ochoco Creek offer appropriate thermal regimes for spawning and rearing anadromous salmonid fishes especially steelhead trout and spring Chinook salmon: (1) the segment immediately downstream of Ochoco Dam to the Red Granary diversion (RM 10.4 to RM 11.1), and (2) the segment downstream of the Combs Flat Road, where OID spills cool water from the Crooked River Diversion Canal, to the Ryegrass diversion (RM 4.7 to RM 5.1).

The reach segment between RM 5.1 and RM 10.4 that includes the Red Granary and Breese diversions and multiple patron pumps is key to evaluating the effects of covered activities. The lowermost reach segment downstream of the Rye Grass diversion (RM 0.0 – 4.7) is less critical as an assessment reach since groundwater infusion to the creek reduces the effect of OID diversions and individual patron pumps (LaMarche 2007).

Following implementation of fish passage facilities at Opal Spring dam, it is possible bull trout may move upstream into this reach when conditions are favorable for foraging (Ratliff et al. 1996). Sockeye salmon are not anticipated to use Ochoco Creek. Sockeye salmon did not use the Crooked River and its tributaries historically. Should sockeye spawning occur in the future they would also likely be limited to areas downstream of RM 18 where they have good access to Lake Billy Chinook for subsequent juvenile rearing.

2.1.8. McKay Creek – Jones Dam to the Mouth of McKay Creek (RM 5.8 – RM 0.0)

2.1.8.1. Overview

McKay Creek joins the Crooked River at RM 44.9. The creek and its tributaries provide more than 50 miles of stream habitat and drain about 103 square miles. Its headwaters lie in the Ochoco National Forest where the best spawning and rearing conditions in the McKay basin can be found.

The reach of interest, designated as Stream Reach 8, lies downstream of the OID District boundary, between the mouth of McKay Creek and Jones Dam (RM 5.8 – RM 0.0) as shown in Figure 2-19. OID spills water into the McKay Creek channel as a delivery method for water users along McKay Creek. This water is generally cool since it is taken from near the bottom of Ochoco Reservoir. The conveyance flow creates an artificial flow beneficial to in-stream resources. Without this flow and other irrigation tailwater, McKay Creek in this reach would likely be dry to the confluence with the Crooked River for the majority of the summer months.

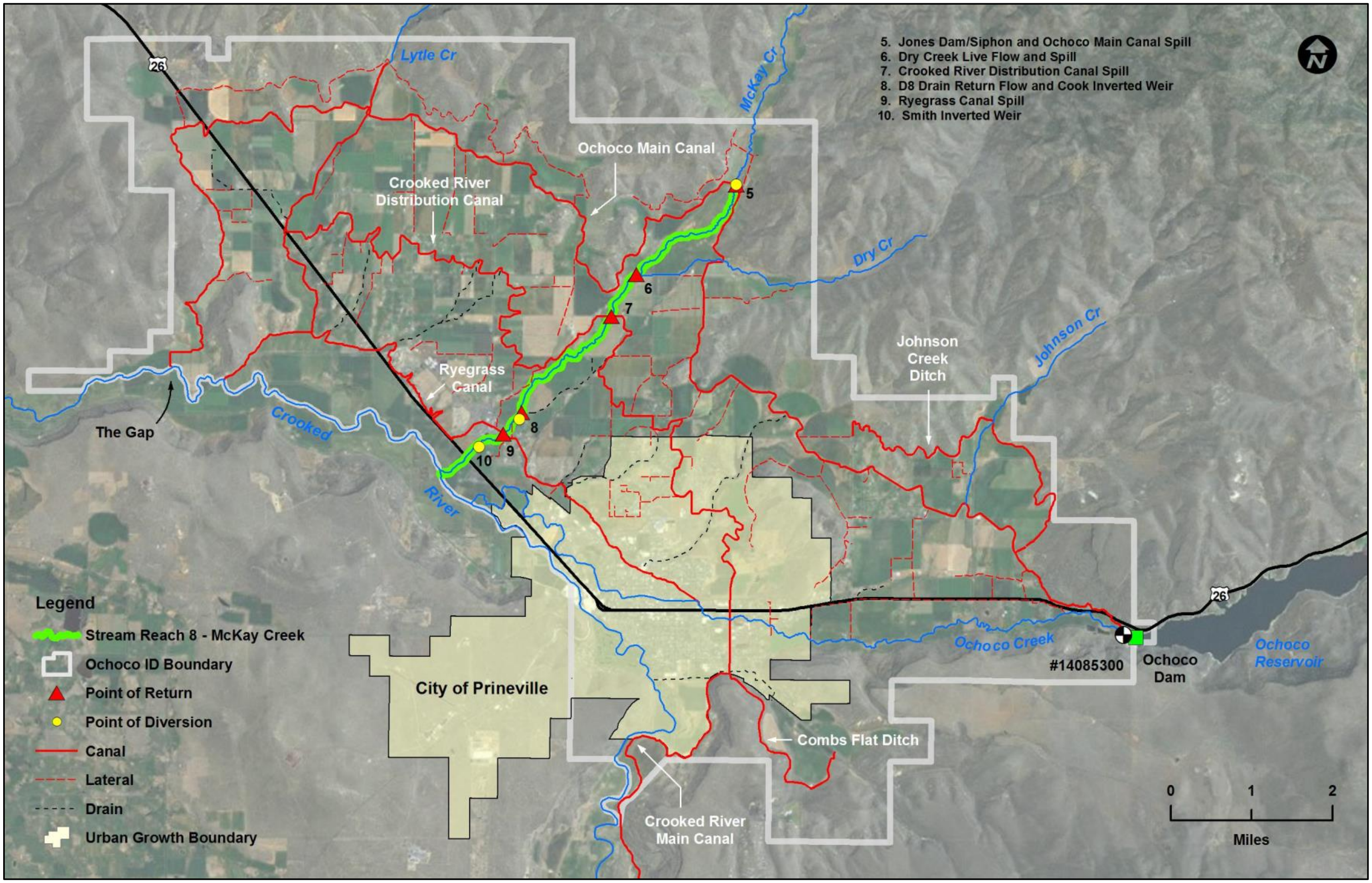


Figure 2-19. Map of Stream Reach 8 from Jones Dam to the mouth of McKay Creek.

2.1.8.2. Channel Characteristics

Stream channel alteration has reduced instream habitat complexity along up to 65 percent of the reach. Instream habitat complexity is limited in much of McKay Creek, with surveys showing pools averaging less than 10 percent of the channel (Walter 2000). Results from a stream sensitivity assessment indicate that 74 percent of McKay Creek shows high channel sensitivity to land use activities or channels that are very responsive to changes in flow, sediment, woody debris, or other inputs (Walter 2000). Channel habitat types in this reach were described by Nielsen-Pincus (2008) consisting of moderate gradient stream channels in broad valley floors constrained within terraces and in some cases land-use berms. The well-defined entrenched channel was dominated by riffle habitats and consisted of 50 percent eroding banks. The current condition in the reach represents a 59 percent loss of the historic meandering channel type.

Many riparian sections along McKay Creek are in a degraded condition. A large portion (15%) of the riparian area is characterized as un-vegetated and the riparian situation is inadequate along nearly 90 percent of stream reaches in the drainage (Walter 2000). Shade along McKay Creek is typically 0-30 percent.

2.1.8.3. Flow Characteristics

Quantitative data on McKay Creek flows are limited due to the lack of permanent measurement stations in the watershed. A permanent stream gauge was operated on McKay Creek downstream of the Allen Creek confluence by the United State Geological Survey (USGS) from 1925 to 1932. In 2007, the Deschutes River Conservancy and the Crooked River Watershed Council financed a stream gauge near the mouth of McKay Creek. Data from this station combined with the historical gauge data provide a preliminary understanding of the McKay Creek hydrology.

McKay Creek flow reflects watershed management and alterations including seasonal water diversions, spills for conveyance of irrigation water, and returns from the irrigation system. Channel straightening, stream corridor degradation, loss of native plants, and irrigation diversions in the McKay Creek system contribute to flashier flows than normal and produce alternatively artificial flows, and low or intermittent flows in this stream reach (Whitman 2002). Flows in McKay Creek are frequently intermittent or dry during the irrigation season, except where OID is spilling or returning tailwater.

Peak flow estimates were calculated for McKay Creek at the mouth for 2-year to 100-year precipitation events (Table 2-4).

Table 2-4. McKay Creek peak flows.

McKay Creek Floods at Mouth (Average Precipitation - 19.14"/yr)						
Return Interval	**2-Yr**	**5-Yr**	**10-Yr**	**25-Yr**	**50-Yr**	**100-Yr**
Flow (cfs)	279	610	859	1,289	1,607	2,277

Source: Nielsen-Pincus (2008)

While peak flows generally occur in the spring, base flows normally occur in late summer or early fall (i.e., August or September). Base flow appears to be about 1.0 cfs and probably ranges from about 0.1 to 1.5 cfs at the mouth of McKay Creek depending on the amount of moisture during the year (Nielsen-Pincus 2008). The portion of McKay Creek (below the National Forest boundary) is often dry by the end of June, or the end of May in dry years. Irrigation diversions upstream of the Ochoco Irrigation District contribute to lack of summer water in McKay Creek. However during dry years, base flows in McKay Creek at the National Forest boundary indicate critical low flows may exist naturally. The surface waters of McKay Creek upstream of the OID boundary can run dry during summer months, depending on seasonal weather conditions and annual snow pack. The recorded mean monthly summer flow in McKay Creek upstream of the OID boundary was approximately 6 cfs, but the reported monthly minimum was 0 cfs (OWRD gage McKay Creek nr Prineville, OR #14086000).

As described above, OID spills water into the McKay Creek channel as a delivery method for water users along McKay Creek. Without this flow and other irrigation returns, McKay Creek in this reach would likely be dry to the confluence with the Crooked River for the majority of the summer months.

2.1.8.4. Fish Habitat

Instream habitat complexity is limited in much of McKay Creek, with surveys showing that pools average less than 10 percent of the channel (Walter 2000). Water temperatures in McKay Creek exceed the State criteria for salmonid spawning and rearing (ODEQ 2002; Nielsen-Pincus 2008), and summer water temperatures typically reach 26.7°C (80°F) in the lower creek. Channel simplification, including bermed and channelized stream reaches, has degraded fish habitat. Stream reaches generally lack instream habitat complexity and riparian corridors are generally degraded. Sedimentation from stream channel erosion and upland sources affects the stream substrate.

Spateholts (2012) estimates this reach of McKay Creek should support a smolt capacity of 810 spring Chinook salmon smolts. Based on an average of 208 steelhead smolts per mile, the steelhead smolt capacity for this reach could equate to 1,105 outmigrants (Spateholts 2012).

2.1.8.5. Key Reach Segments

Without irrigation spills and returns provided by the DBHCP, it is likely this reach of McKay Creek would go dry during the summer months, resulting in a lack of habitat for fish production. Whereas covered fish species, especially steelhead trout and spring Chinook salmon, could use the habitat seasonally without the covered activities, the late summer release of irrigation waters in McKay Creek provides year-round rearing habitat. Although water quality is limited, the best estimates for spring Chinook salmon and steelhead trout production occur in the lowermost mile of the stream downstream of the Ryegrass Canal spill (RM 0.0- RM 1.0) and downstream of the Crooked River Distribution Canal spill at Reynolds between RM 2.3 and RM 3.2 (Quesada et al. 2012; Spateholts 2012).

The reach segment between RM 3.2 and RM 5.8 that includes the influence of the Jones diversion prior to the Reynolds spill and the reach from the Smith diversion to the mouth (RM 0.0 to RM 0.6) are key to evaluating the effects of covered activities. The lowermost reach segment downstream of the Smith diversion is less critical as an assessment reach since groundwater infusion to the creek reduces the effect of OID diversions (LaMarche 2007).

Following implementation of fish passage facilities at Opal Spring dam, it is possible bull trout may move upstream into this reach when conditions are favorable for foraging (Ratliff et al. 1996). Sockeye salmon are not anticipated to use McKay Creek. Sockeye salmon did not use the Crooked River and its tributaries historically. Should sockeye spawning occur in the future they would also likely be limited to areas downstream of RM 18 where they have good access to Lake Billy Chinook for subsequent juvenile rearing.

2.1.9. Lytle Creek – Ochoco Main Canal to the Mouth of Lytle Creek (RM 5.0 – RM 0.0)

2.1.9.1. Overview

Lytle Creek is a tributary to the Crooked River at RM 41.0 (Figure 2-20). The creek is generally dry immediately above the OID boundary, but within the district (Stream Reach 9) it flows year round. The majority of flow within district is operational spill and return water during the irrigation season, but a small amount off spring-fed live flow emerges from the D7 drain a short distance above Highway 26 throughout the year. OID uses the creek as a conveyance system and also diverts stream flow when live flows occur during the irrigation season. Four irrigation spills from the Ryegrass, Crooked River Distribution, Ochoco Main, and Grimes Flat West canals have the potential to flow into Lytle Creek at RM 1.3, 3.0, 5.0, and 5.7, respectively. There are also four irrigation drains (Drain 823, 825, 827, and D-7) returning flow to the creek between RM 1.5 and RM 3.2.

The lower 1.3 miles of Lytle Creek are merged with the Ryegrass Canal into a man-made ditch that flows into the Crooked River. The lowermost diversion in this section, consisting of a check-dam structure with stop logs, occurs at RM 0.5 (Photo 3). The City of Prineville's railroad crosses Lytle Creek at RM 0.4.

Photo 3. Lytle Creek lowermost check-dam structure at RM 0.5 (July 11, 2012). Q = 4.4 cfs.

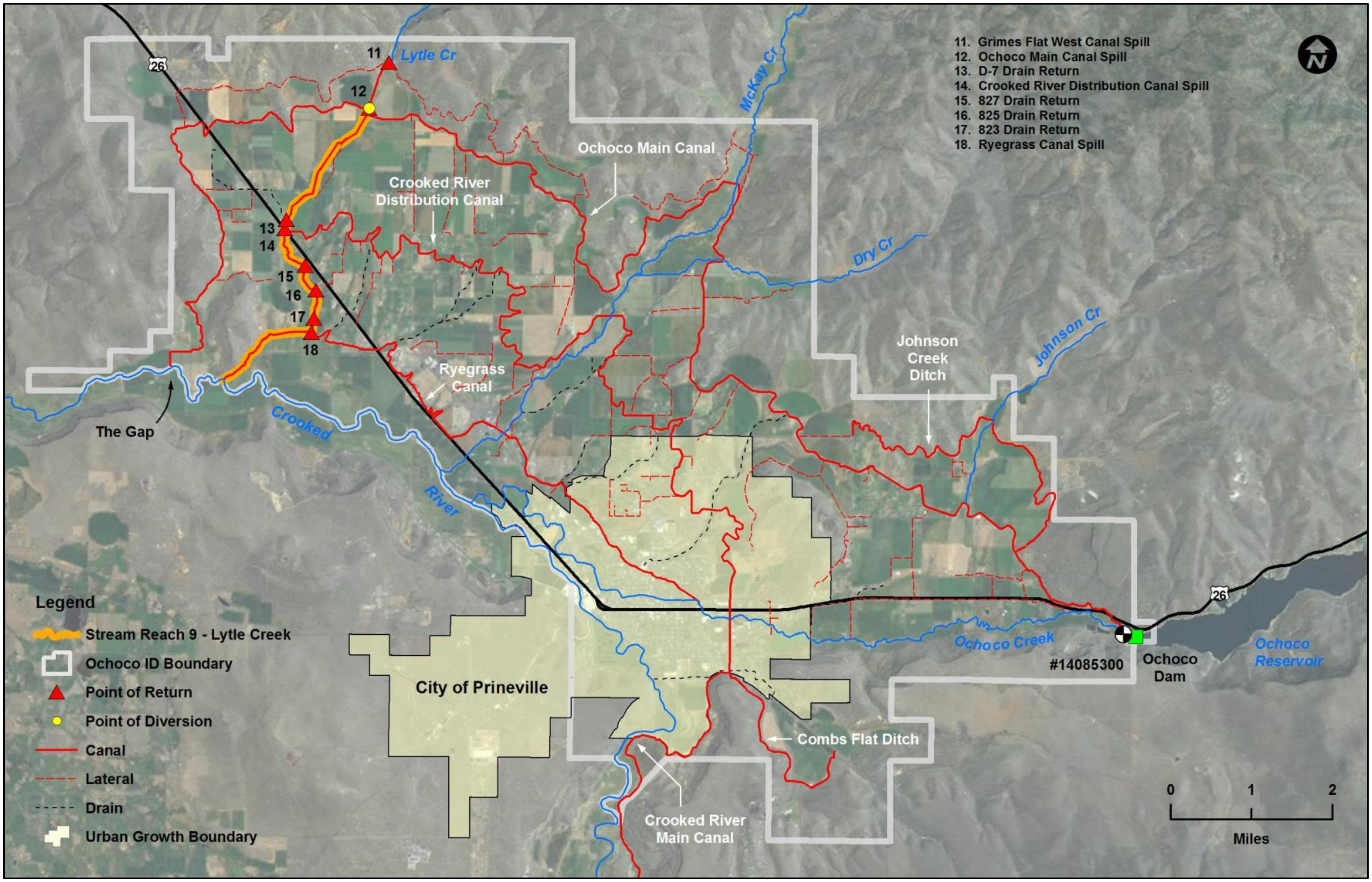


Figure 2-20. Map of Stream Reach 9 from Ochoco Main Canal to the mouth of Lytle Creek.

2.1.9.2. Channel Characteristics

Lytle Creek has been modified for irrigation conveyance purposes (Photo 4). Downstream of the check-dam structure, the creek is constrained between an access road and the City's railroad ROW. The channel is approximately 10 feet in width and fairly well-entrenched at this point. Maximum summer water depths of 1 to 1.5 feet are typical, as noted during a site visit of July 11, 2012, when 4.4 cfs of stream flow was measured passing the check-dam (Photo 3). Rip-rap is used to support the various structures and to shore-up bank failures or scour points (Photo 5). The ditch is well-vegetated with abundant bank cover (Photo 6). The substrate consists of mostly rubble and rock with heavy filamentous periphyton growth during summer months. There are small amounts of gravel accumulations downstream of the railroad crossing, where stream gradients increase, and where springs enter the channel. Silty streambed conditions prevail where channel gradients are reduced and water velocities are diminished. Crooked River flow elevations create backwater conditions approximately 1,000 feet upstream in Lytle Creek (RM 0.2). In such low velocity conditions, muddy banks and silty sediments prevail in a palustrine channel type.

Photo 4. Lytle Creek downstream of the Crooked River Distribution Canal at RM 3.0 (May 26, 2005).

Photo 5. Lytle Creek at approximately RM 0.3 downstream of railroad crossing (July 11, 2012).

Photo 6. Lytle Creek upstream of the check-dam at RM 0.5 (July 11, 2012).

2.1.9.3. Flow Characteristics

Lytle Creek runs 6 to 10 cfs during winter mostly due to groundwater seepage interception and subsequent spill by the irrigation canals. During the summer months, Lytle Creek often goes dry upstream of the OID boundary, but receives irrigation return flows and spills at the various canal crossings within the district. There are 11 points of diversion from Lytle Creek consisting of OID diversion at the canal crossings and individual patron diversions mostly at check-dam structures with stop logs or via individual pumps.

The water in Lytle Creek at the confluence with the Ryegrass Canal is almost entirely water that has entered the creek from the Crooked River Distribution Canal and Ochoco Main Canal. During a July 11, 2012 site visit, flow in Lytle Creek was running 1.4 cfs at the telemetered site (RM 5.0) and 4.4 cfs past the check-dam with stop logs (RM 0.5).

2.1.9.4. Fish Habitat

Little is known regarding the fish habitat characteristics of Lytle Creek. The creek channel has been modified and flow levels have been adjusted for irrigation conveyance purposes. The tributary is relatively small and likely not always suitable for Chinook salmon or bull trout spawning. Steelhead trout could make use of the stream at least up to the Ochoco Main canal at RM 5.0, and perhaps upstream to Fisher Joe Reservoir (RM 6.3) during the non-irrigation season when stop logs are removed from the various structures.

Habitat conditions in the lower 0.5 river mile were qualitatively reviewed during a July 11, 2012 site visit. The lowermost 0.2 mile of backwatered palustrine channel should be regarded as migration and low-velocity rearing habitat. Limited spawning habitats are distributed between RM 0.2 and RM 0.4 where stream gradients and water velocities increase. Upstream of RM 0.4, the streambed is mostly rubble and of limited value for spawning, although fairly productive for rearing steelhead trout. The state of Oregon categorizes Lytle Creek as water temperature-limited its entire length downstream of RM 4.2 (ODEQ 2002).

2.1.9.5. Key Reach Segments

Without irrigation spills and returns, it is likely the lowermost 5-mile reach of Lytle Creek would become dry during the summer months, resulting in a lack of habitat for fish production. Whereas covered fish species could use the habitat seasonally without the covered activities, the late summer release of irrigation waters offers potential for year-round fish rearing habitat. Although water quality-limited, the largest quantity of water and the best likelihood for steelhead trout production occurs in the lowermost mile of the stream downstream of the Ryegrass Canal spill (RM 0.0- RM 1.0), which is a key area for evaluating the effects of covered activities.

Spring Chinook, bull trout and sockeye salmon are not anticipated to use Lytle Creek. The tributary is likely too small to attract Chinook salmon. Following implementation of fish passage facilities at Opal Spring dam, it is possible bull trout may move upstream into this reach when conditions are favorable for foraging (Ratliff et al. 1996). Sockeye salmon did not use the Crooked River and its tributaries historically. Should sockeye spawning occur in this basin in the future, they would also likely be limited to areas downstream of RM 18 where they have good access to Lake Billy Chinook for subsequent juvenile rearing.

2.2. Available Data Sets

Some level of instream flow assessment has occurred at every mainstem river reach and in some tributary waters historically accessible to covered fish species in the Deschutes basin. Three mainstem reaches in the Crooked River Basin were evaluated using the IFIM/PHABSIM study methods in 1993 for rainbow trout, and reassessed in 2001 for Chinook salmon and steelhead trout (Hardin 1993, 2001). One mainstem Deschutes River reach between the Pelton Reregulating Dam and the confluence of Trout Creek was evaluated by PGE (2001) using a wetted perimeter approach (Nelson 1980) for juvenile rearing and an effective toe-width approach for spawning steelhead trout (Swift 1976, 1979). The remaining reaches were reviewed using the Oregon Method in the early 1970s (Lauman and Pitney 1973). Most of these reaches have existing instream water rights established between 1983 and 1990, or water rights that are currently pending. Although instream flow water right claims have been established according to the Oregon Method for mainstem waters throughout the defined restoration area for the covered fish species, the original flow and hydraulic channel data are no longer available. As a result, there are no existing data related to the Oregon Method in the Deschutes Basin to evaluate herein. The available data sets for the four reaches with instream flow assessments are evaluated in the Deschutes and Crooked rivers in the subsequent sections.

2.2.1. Crooked River Reaches

Hardin (1993) collected channel transect and flow data from three reaches in the Crooked River shown in Table 2-5 and highlighted in Figure 2-1.

Table 2-5. Crooked River reaches with available IFIM/PHABSIM study data.

Number	Name	Location	River Mile
4	Upper Canyon	Bowman Dam to CRK R. Diversion	70.5 - 57.0
5	Prineville Valley	CRK R. Diversion to NUID Pumps	57.0 - 27.6
6	Lower Canyon	NUID Pumps to Hwy 97	27.6 - 18.0

Using habitat suitability indices for steelhead trout and Chinook salmon, Hardin calculated the relationship between weighted useable area of habitat (WUA) and river discharge for various life history stages of these species in each river segment. The resulting WUA versus flow curves for spawning and juvenile rearing are shown in Figures 2-21 through 2-26.

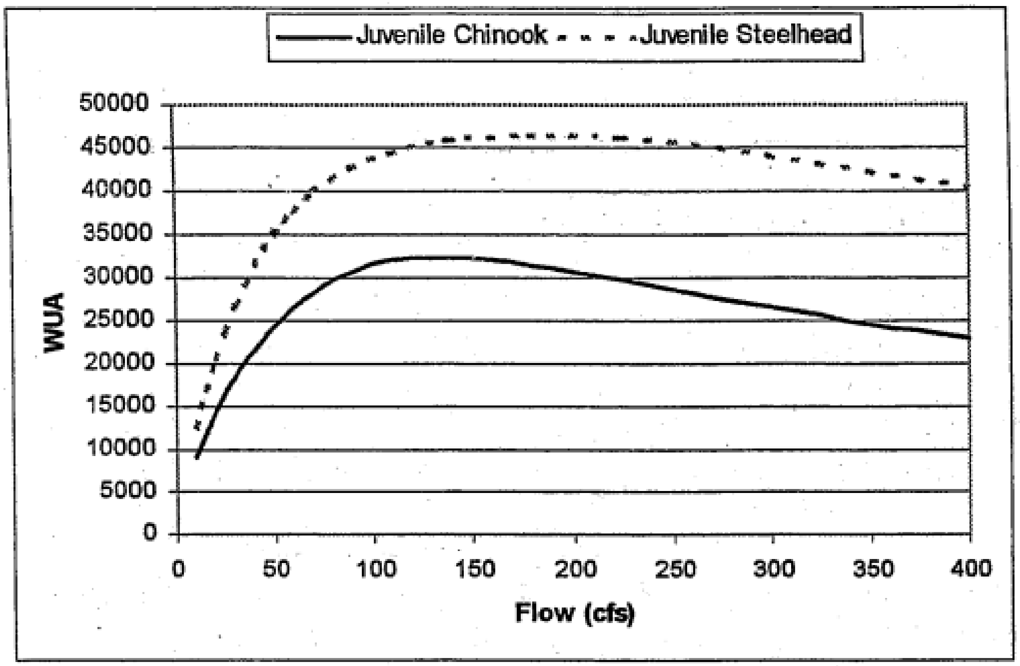


Figure 2-21. WUA vs. flow for juvenile Chinook salmon and steelhead trout rearing in the Upper Canyon Segment.
Source: Hardin (2001)

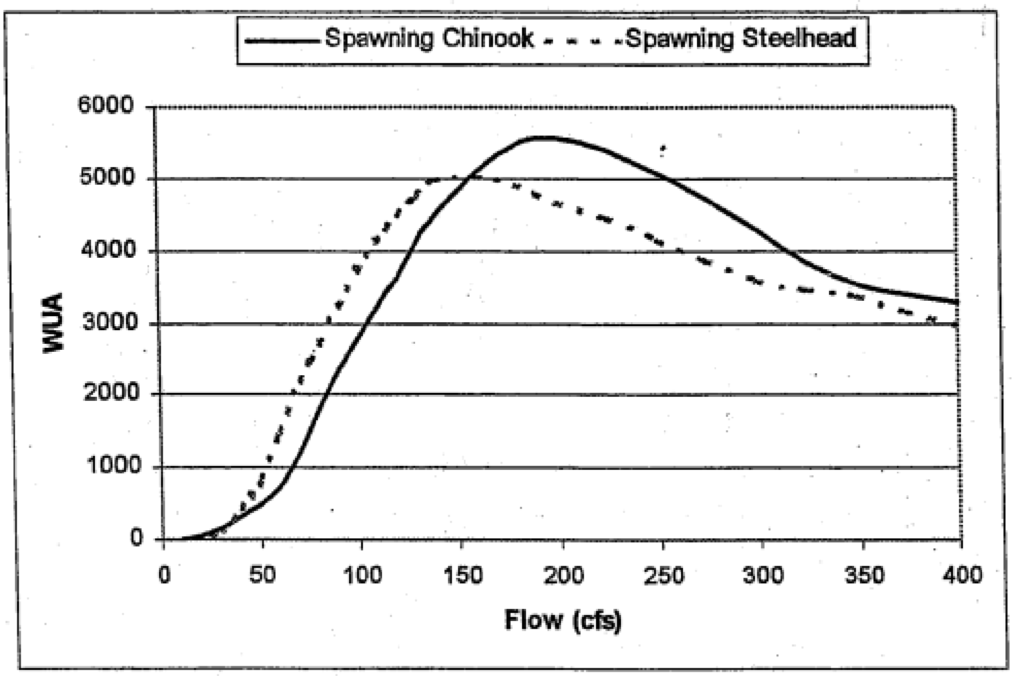


Figure 2-22. WUA vs. flow for Chinook salmon and steelhead trout spawning in the Upper Canyon Segment.
Source: Hardin (2001)

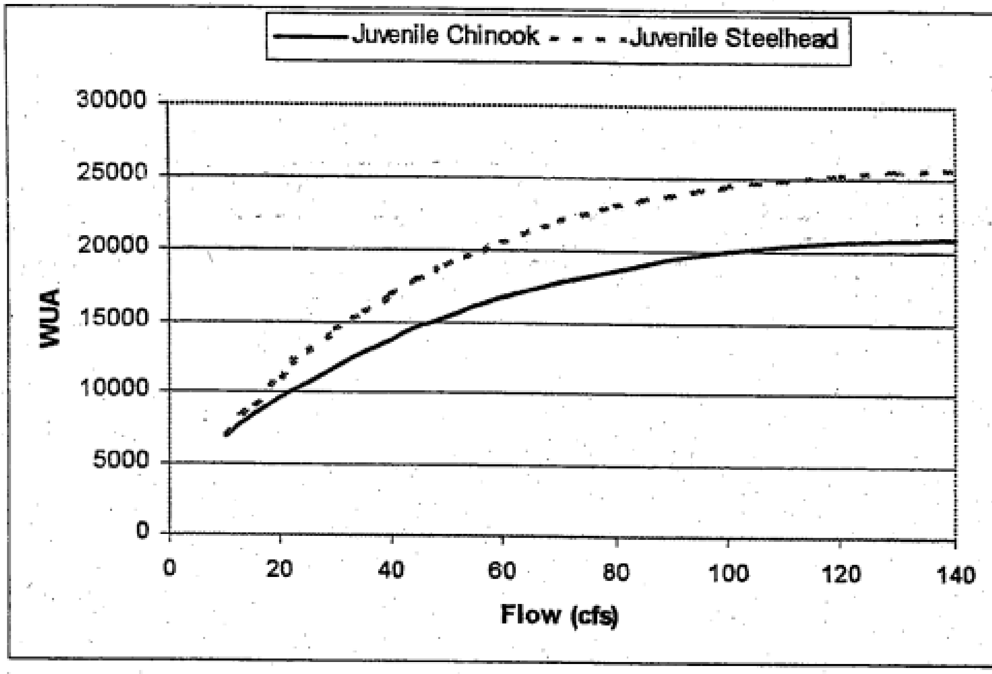


Figure 2-23. WUA vs. flow for juvenile Chinook salmon and steelhead trout rearing in the Prineville Valley Segment.
Source: Hardin (2001)

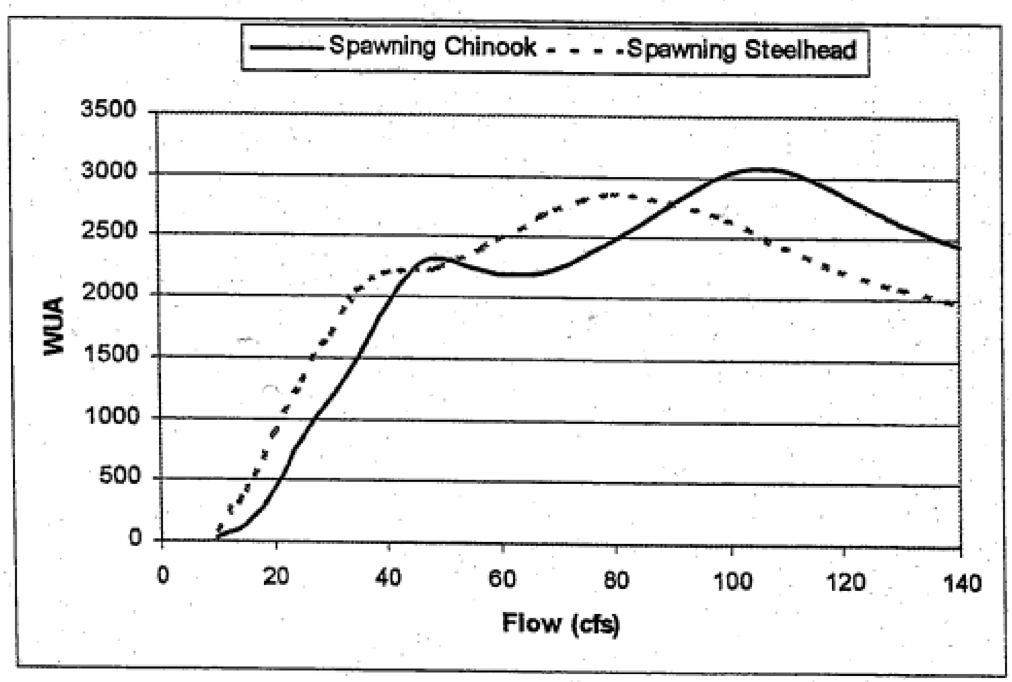


Figure 2-24. WUA vs. flow for Chinook salmon and steelhead trout spawning in the Prineville Valley Segment.
Source: Hardin (2001)

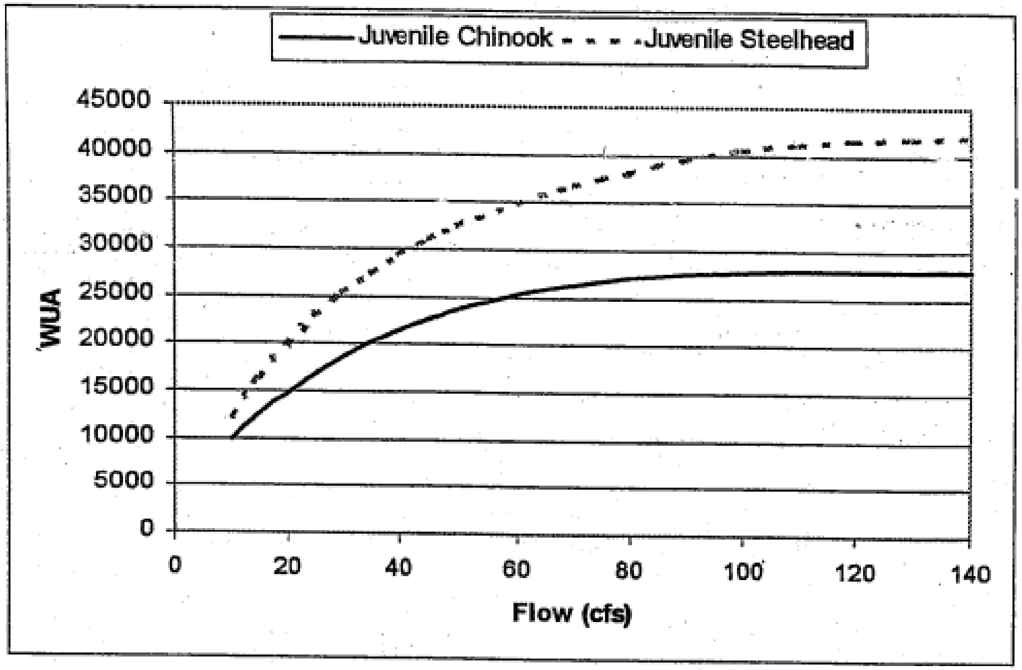


Figure 2-25. WUA vs. flow for juvenile Chinook salmon and steelhead trout rearing in the Lower Canyon Segment.
Source: Hardin (2001)

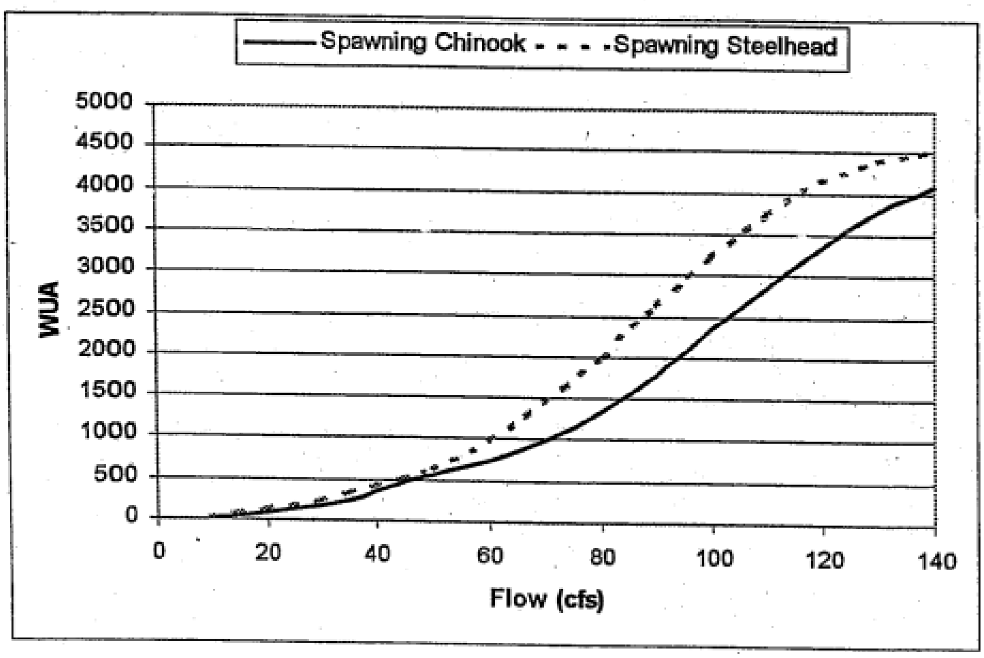


Figure 2-26. WUA vs. flow for Chinook salmon and steelhead trout spawning in the Lower Canyon Segment.
Source: Hardin (2001)

Data regarding the number and representative habitat types of various cross-channel transects in the three study segments are included in Appendix A (Tables A-1 to A-5). The data summary indicates there exist a complete set of three flow measurements, habitat mapping, sufficient numbers of transects measured to represent the available habitats, river velocities measured at the middle calibration flow, and a good extrapolation range for model simulation between 10 and 400 cfs at the Upper Canyon Segment (Table A-2).

The channel reaches of Prineville Valley and the Lower Canyon offer a more limited data set, with only two flow measurements, and river velocities measured at the lowest calibration flow. This limitation means the extrapolation of the model simulation is restricted to the reported flow range between 10 and 140 cfs (Tables A-3 and A-4). In addition, the Prineville Valley reach has a restricted number of transects, lacks habitat mapping tied specifically to the individual transects, and water surface elevations (WSEs) were not reported.

The analysis of flow effects for the Crooked River will be limited to evaluating the differences between regulated and unregulated flows. The range of unregulated flow estimates in the Valley and Canyon reaches, based on the work of WPN (2011), lies between 25 and 1,050 cfs. The lower value represents the median monthly flow for September downstream of the OID Crooked River diversion and the highest value represents the median monthly flow for April downstream of the Ochoco Creek confluence as well as downstream of the NUID pumps. The range of current regulated flows in the Valley and Canyon reaches on a median monthly basis lies between 35 and 600 cfs over the same locations and time periods.

The WUA vs. discharge relationships developed by Hardin for the Prineville Valley and Lower Canyon reaches can be used for DBHCP purposes when the scenarios to be tested fall within the flow simulation range of less than 140 cfs. The model could be expanded with further field data collection related to additional transects and a wider range of measured water surface elevations and velocity profiles compared to the original IFIM study effort. Conversely, the existing and additional transect information for the Valley and Lower Canyon reaches could be used with surrogate hydrological methodologies.

2.2.2. Deschutes River Reaches

NMFS (2005), using PGE (2001) data, performed a spawning and rearing habitat assessment for the lower Deschutes River between the Pelton Reregulating Dam at RM 100 and the confluence of Trout Creek (RM 87.2). They conducted a wetted perimeter hydrological approach (see Section 2.4.1 *Wetted Perimeter*, below for a review of the methodology). PGE documented the change in water surface elevation (WSE), total channel width (top width), and wetted channel perimeter (WP) at five sites in this key reach segment of the lower river. Changes in these parameters were recorded at 500 cfs flow increments between 3,500 and 8,000 cfs. NMFS extrapolated results between these flow increments based on USBR MODSIM modeled flow scenarios. Habitat effects were assessed by calculating the area of river bottom exposed at the various flow scenarios. The change in wetted perimeter was averaged over the five sites and the exposed area was calculated over the total distance of 7.8 miles between the sites. The results represent the reduction in available juvenile rearing habitat area (acres) for the 50 percent exceedance levels of the flow scenarios NMFS studied (Table 2-6).

PGE (2001) also performed a spawning habitat availability study at six cross-sections in active steelhead spawning areas in the 7.8-mile segment. Available spawning area was based on habitat suitability indices (HSIs) for steelhead trout using suitable spawning depths of 1.1 to 2.8

feet, and suitable spawning velocities of 1.3 to 3.3 feet per second (fps). Spawning area was evaluated at 1,000 cfs increments between 3,500 and 6,000 cfs. This approach is similar to the original Toe-Width method for salmonid fish spawning habitat (Swift 1976, 1979) (see Section 2.4.2 *Toe-Width Method* below for a review of the methodology). For the flow scenarios tested, spawning habitat availability trends varied at the individual cross-sections and no clear, direct relationship between a change in river discharge and spawning area could be determined (NMFS 2005).

Table 2-6. Example of rearing habitat changes at different flow levels on 7.8 miles of the Deschutes River between the Pelton Reregulating Dam and Trout Creek using a Wetted Perimeter approach.

Month	Change in Mean Monthly 50% Exceedance Flow Levels between Scenarios (cfs)	Reduction in Rearing Habitat between Flow Scenarios (acres)
October	-392	2.2
November	-573	3.7
December	-382	1.6
February	-453	1.8
March	-761	3.1
April	-732	3.0

Source: NMFS (2005).

2.3. Data Gaps

Gaps in available instream flow datasets for the coincident reaches with covered fish species are summarized below:

2.3.1. Deschutes River – Big Falls to Lake Billy Chinook (RM 132 – RM 120)

There are no available instream flow study data available for this reach. Cross-sectional transect data are present at the Deschutes River gage at Culver (USGS # 14076500) where stage/discharge rating curves have been developed. Additional transect data would be needed to relate flow effects to habitat for covered fish, especially from riffle habitats important for spawning and rearing and especially from the key reach segments identified in Section 2.1.1.5, *Middle Deschutes River Key Reach Segments*.

2.3.2. Deschutes River – Pelton Re-regulating Dam to the Mouth of the Deschutes River (RM 100 – RM 0.0)

There are instream flow study data available for this reach. PGE established cross-sectional transects across 7.8 miles of the Deschutes River between the Pelton Reregulating Dam and Trout Creek; a key reach segment identified in Section 2.1.2.5, *Lower Deschutes River Key Reach Segments*, above. PGE gathered these data in support of re-licensing of the Pelton Round Butte Project (PGE 2001 as reported in NMFS 2005). Additional cross-sectional data in this reach were collected during a lower river gravel study performed for PGE by Stillwater Sciences (Stillwater 2007). These hydraulic datasets could be used in future instream flow assessments. In the biological opinion of the USBR Biological Assessment for Ongoing Operations and Maintenance of the Deschutes River Basin Projects, NMFS (2005) used the PGE cross sections to perform a wetted perimeter rearing habitat assessment as well as an HSI spawning area approach with transects through riffle spawning habitats at six sites. The transect data are available in the Stillwater (2007) study report and are sufficient for DBHCP purposes for the key reach segment in the Lower Deschutes River.

There are also three transect measurements available from the USGS for rating their Deschutes River gage at Madras (#14092500). These transects have been evaluated in a wetted-perimeter approach in Appendix B. Although helpful, these data are less valuable for the instream flow evaluation than PGE's transects that include riffle habitat types.

2.3.3. Whychus Creek – Plainview Ditch to the Mouth of Whychus Creek (RM 25.9 – RM 0.0)

There are no instream flow study data available for this reach. Three cross-sectional transect measurements are present at the Whychus Creek gage near Sisters (USGS # 14075000) where stage/discharge rating curves have been developed. This gage is located upstream of the TSID's Whychus Creek diversion. Transect data from lower in the watershed are available from OWRD gages, the USFS, various channel restoration studies, and FEMA flood studies near the City of Sisters that are more useful for the DBHCP flow evaluation. Available transect data, especially from riffle habitats important for spawning and rearing life histories of covered fish species are organized separately into the three channel segment types identified in Section 2.1.3.5, *Whychus Creek Key Reach Segments* above.

The Upper Deschutes Watershed Council (UDWC) is planning to conduct extensive transect work in the creek during the summer of 2013 to document post-restoration channel characteristics at Camp Polk (Houston, UDWC pers. comm. October 2012). These data would represent current channel conditions and would be most valuable for the ongoing restoration efforts performed in recent years in Whychus Creek. Depending upon channel and habitat restoration efforts, the existing cross-sectional transects may represent old channel conditions. The UDWC transect data would be most useful in performing DBHCP instream flow assessments.

2.3.4. Crooked River– Bowman Dam to the Crooked River Diversion (RM 70.5 – RM 57.0)

There are no data gaps in this reach of the Crooked River. Instream flow study data are available for this reach. Hardin (1993, 2001) performed IFIM/PHABSIM modeling for steelhead trout and Chinook salmon in what he called the ‘Upper Canyon’ reach. The available information has been reviewed and found to be sufficient for use by the DBHCP for an instream flow evaluation.

There are also three transect measurements available from the USGS for rating their Crooked River gage near Prineville (#14080500). Although helpful, these data are less valuable for the instream flow evaluation than Hardin’s IFIM model because they are measured especially at locations suitable for discharge measurement rather than at representative fish habitat types.

2.3.5. Crooked River – Prineville Valley Reach; Crooked River Diversion to NUID Pumps (RM 57.0 – RM 27.6)

Instream flow study data are available for this reach. Hardin (1993, 2001) performed IFIM/PHABSIM modeling for steelhead trout and Chinook salmon in the ‘Prineville Valley’ reach. The utility of the information for instream flow evaluation purposes is somewhat limited due to:

- Limited number of transects
- Lack of habitat mapping tied to transect data associated with the instream flow study
- Only two river flows were measured
- No water surface elevations were recorded
- Limited extrapolation of model simulation (10 to 140 cfs) due to use of calibration flows at the lowest measured river flow level
- Lack of habitat versus flow resolution within 140 cfs

Since the difference between regulated and unregulated flows in this reach exceeds 140 cfs between February and June annually, additional transect and flow level measurements would be useful to extend the range of extrapolation. The existing and additional transect information could be used with either IFIM or surrogate instream flow methodologies.

The NRCS (2010) performed a hydrological assessment of a major portion of this reach for the Crooked River Watershed Council, using LiDAR and HEC-RAS modeling. Transect information from that assessment have been requested from the CRWC. If available, such data would assist in filling the aforementioned data gap.

2.3.6. Crooked River – NUID Pumps to Highway 97 (RM 27.6 – RM 18.0)

There are instream flow study data available for this reach consisting primarily of the Hardin (1993, 2001) IFIM/PHABSIM analysis completed in the ‘Lower Canyon’ reach. These data are useful but have some limited applicability for the instream flow analysis due primarily to limits of extrapolation (approximately 10 to 140 cfs).

Since the difference between regulated and unregulated flows in this reach exceeds 140 cfs between February and June annually, additional transect and flow level measurements would be useful to extend the range of extrapolation. The existing and additional transect information could be used with either IFIM or surrogate instream flow methodologies as a means to evaluate flow effects.

2.3.7. Ochoco Creek – Ochoco Dam to the Mouth of Ochoco Creek (RM 10.5 – RM 0.0)

There are no instream flow study data available for this reach. Cross-sectional transect measurements exist for the OWRD gage - Ochoco Creek below Ochoco Reservoir (OWRD # 14085300) where stage/discharge rating curves have been developed. This gage is located immediately downstream of the Ochoco Dam and the data will be useful for the flow evaluation. The transect data for development of the rating curves have been requested from the OWRD. However, transect data collected from specific habitats important for spawning and rearing will be needed to allow development of habitat-flow relationships for covered fish species.

2.3.8. McKay Creek – Jones Dam to the Mouth of McKay Creek (RM 5.3 – RM 0.0)

There are no instream flow study data available for this reach. Cross-sectional transect measurements exist for the OWRD gage (McKay Creek near Prineville, OR; OWRD # 14085300) where stage/discharge rating curves have been developed. This gage is located upstream of the covered lands. Thus, transect data collected from specific habitats important for spawning and rearing will be needed within the key reach segments to allow development of habitat-flow relationships for covered fish species.

2.3.9. Lytle Creek – Ochoco Main Canal to the Mouth of Lytle Creek (RM 5.0 – RM 0.0)

There are no instream flow study data available for this reach. Thus, transect data collected from specific habitats important for spawning and rearing will be needed to allow development of habitat-flow relationships for covered fish species. To relate flows to habitat for covered fish species in this reach, transects from riffle habitats in the key reach segments identified in Section 2.1.9.5, Lytle *Creek Key Reach Segments* would be desirable, but of low priority.

2.4. Assessment Tools

Study 11 – Phase 2 will provide an evaluation of habitat effects on a site-specific basis using one or more assessment tools. Tools and approaches available for evaluating potential changes in habitat with flow alterations are addressed in the sections below.

Of the habitat methods available, IFIM (Bovee 1982, Stalnaker et al. 1994) and its associated computer programs, PHABSIM, are the most widely used in North America (Reiser et al. 1989). Based on the use of habitat suitability indices (HSI), IFIM is also biologically-based and one supportable approach for the Services to document the biological rationale in their incidental take permit (ITP) and Biological Opinion (BiOP) for the DBHCP. Other methods commonly applied in the western states include: Tennant or Montana method (Tennant 1975, 1976) as adapted by Tessman (1980); Toe-Width method developed for western Washington streams (Swift 1976, 1979; as updated by Washington State Department of Ecology 2009); Oregon Method (Thompson 1972), the Wetted Perimeter method (Nelson 1980); and the Indicators of Hydrologic Alteration (IHA) (Richter et al. 1996; The Nature Conservancy 2007). The advantages and disadvantages of several of these and other instream flow assessment tools have been reviewed and summarized in the DBHCP Gap Assessment Report (as itemized in Table 4 of Biota Pacific et al. 2011).

With respect to evaluating activities that influence flows in streams that contain (or will contain) covered fish species within the covered lands, the selection of a particular method should be based on its ability and reliability to: 1) effectively address the resource objectives, 2) evaluate incremental changes in habitat with changes in stream flow, and, 3) provide results that can be used as an effective habitat surrogate for incidental take. Based on the initial review of various methods available for estimating instream flow levels for maintenance of fish habitat, the following methods were identified in the DBHCP Gap Assessment for the flow assessment of existing impacts and future conservation measures (Biota Pacific et al. 2011):

Hydrologic-Based Methods

Montana/Tennant Method

Tessman Method

Indicators of Hydrologic Alteration (IHA)

Channel-Based Methods

Wetted Perimeter

Toe-Width Method

Biological-Based Methods

Thompson (Oregon) Method for adult upstream passage

Instream Flow Incremental Methodology / Physical Habitat Simulation

These approaches are reviewed below with respect to their utility for evaluating the current effects of covered activities and potential benefits of DBHCP conservation measures related to instream flow. The information will be used in future discussions with the DBHCP Working Group as the basis for recommending an appropriate assessment methodology.

Based on a review of potential methods, it is recommended the site-specific adaptations of the Oregon Method (Thompson 1972) be used for evaluating the effects of flow on upstream passage of migrating adults. Because this method is widely applied and accepted for determining suitable flows for upstream passage, a detailed assessment of the methodology is not provided herein. Rather, the review focuses on methods for evaluating flow relationships on spawning and rearing habitats of covered fish species.

Hydrologic-based metrics are not incremental and generally lack a direct, quantifiable linkage to biological habitats. As a result, the application of solely hydrologic-based methods makes it difficult to support a biological rationale as a habitat surrogate. Consequently, reliance on the Tennant, Tessman, or IHA approaches is not recommended for DBHCP purposes and these methods are not discussed further in this report.

In contrast, the channel based approaches are founded on elements that can be linked to biological benefits. Site-specific assessments of the channel-based methods are evaluated below with respect to their applicability for filling data gaps.

2.4.1. Wetted Perimeter

The distance from water's edge to water's edge along the bottom of the channel is defined as the wetted perimeter (WP) of the channel. This hydraulic variable changes with flow and a variety of biological benefits have been ascribed to increasing the amount of wetted perimeter (Nelson 1980). In this hydraulic approach, flow values are associated with a habitat index that incorporates stream channel characteristics. The wetted perimeter technique generally addresses the wetted bottom of the stream cross section that is estimated to protect the habitat needs, frequently defined as a limiting characteristic, such as a riffle habitat area.

An area is selected as an index of habitat that is considered representative of the stream reach. Often a riffle is used as the indicator since riffles are important for food production, fish passage, and spawning. Thus, increases in wetted perimeter within these areas presumably will benefit other habitat areas in the stream such as pools and runs. The wetted perimeter versus discharge relationship can be used for defining flows considered acceptable for the maintenance of aquatic habitats. This relationship has been estimated by defining the inflection point on the wetted perimeter – flow curve. The inflection point represents the flow below which the wetted perimeter begins to decrease sharply. Identifying the inflection point is scale-dependent and somewhat subjective depending upon the shape of the channel. The subjectivity can be overcome by defining the break in shape using mathematical techniques (Gippel and Stewardson 1998). The wetted perimeter versus flow curve would allow an incremental assessment of flow changes associated with DBHCP conservation measures.

2.4.1.1. Biological Surrogate

The wetted perimeter method assumes biological productivity is related to wetted area. The method is founded on the assumption that food supply can be a major factor influencing a stream's carrying capacity during the non-winter months. The principal food of many salmonid fishes is aquatic invertebrates, which are produced primarily in stream riffle areas. The method assumes the fish carrying capacity is related to food production, which in turn is related to the amount of wetted perimeter in riffles (Leathe and Nelson 1986). An example of this concept is provided in Figure 2-27. While this example focuses on food production, the wetted perimeter also relates to other factors such as bank cover, as well as spawning and rearing habitat. As shown by NMFS (2005), the wetted perimeter approach can be used to estimate the amount of rearing space either inundated or conversely, exposed at various flow scenarios.

2.4.1.2. Site-specific Application – Example Reaches

Applying the wetted perimeter approach to riffle cross-sections in various example reaches results in the wetted perimeter versus flow curves that are included in Appendix B. Examples are shown in Figures 2-28 through 2-32 for five reaches. The wetted perimeter curves shown in these figures can be used to assess incremental changes in flow relative to wetted perimeter under various DBHCP scenarios.

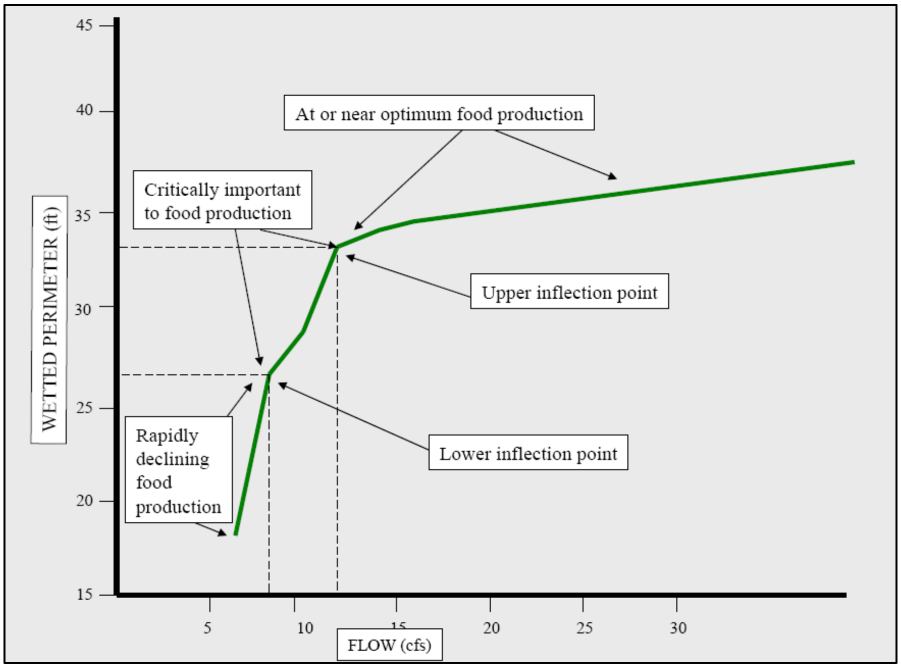


Figure 2-27. An example of a relationship between wetted perimeter and flow for a stream riffle cross-section showing upper and lower inflection points.
Source: Leathe and Nelson (1986)

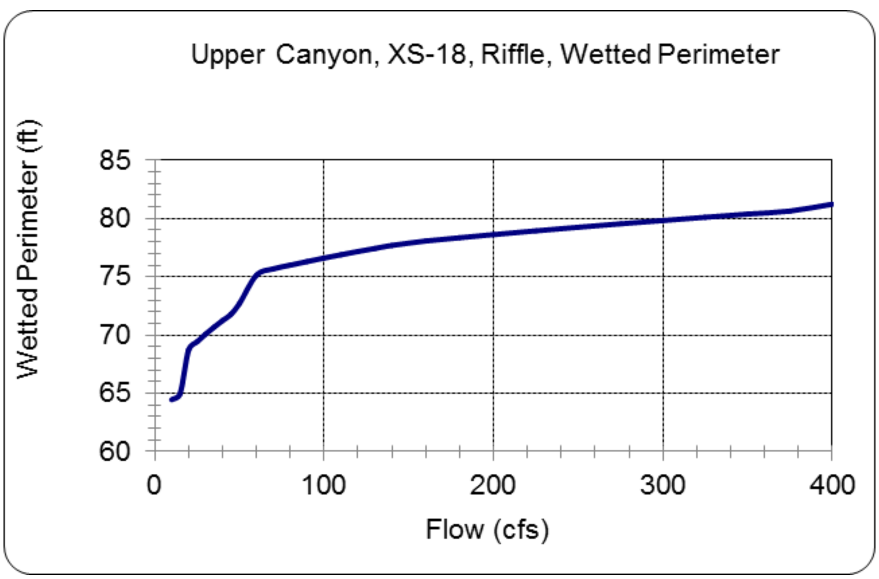


Figure 2-28. Example of the incremental change in wetted perimeter (feet) with flow at cross-section (NSO #18) in the Upper Canyon Reach of the Crooked River downstream of Bowman Dam.
Source: Huang (2012)

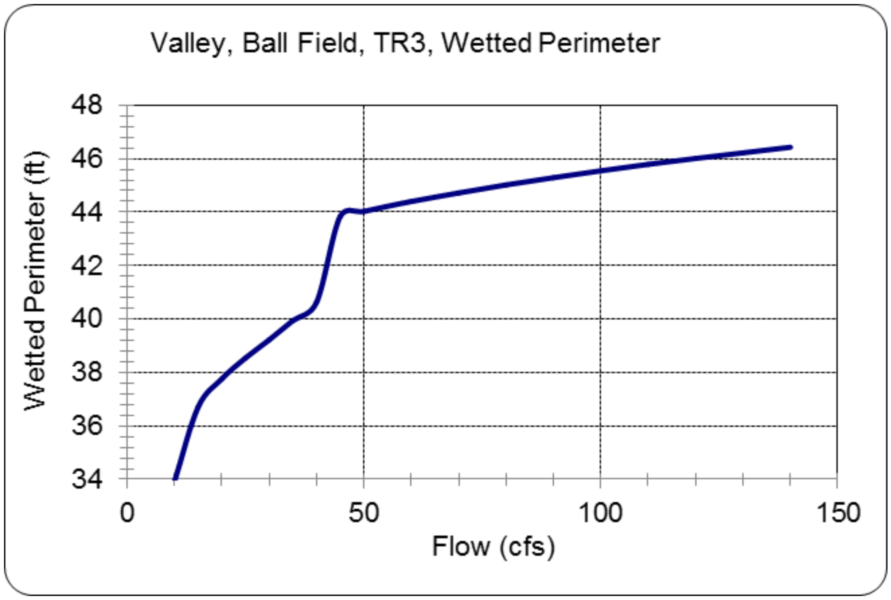


Figure 2-29. **Example of the incremental change in wetted perimeter (feet) with flow at cross-section (NSO #BF-3) in the Prineville Valley Reach of the Crooked River downstream of the Crooked River Diversion.**
Source: Huang (2012)

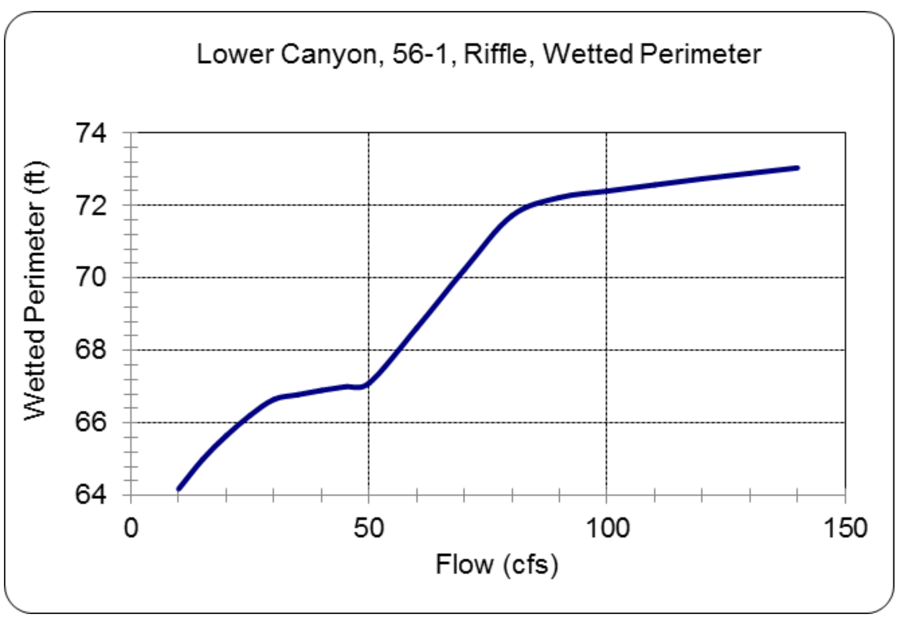


Figure 2-30. **Example of the incremental change in wetted perimeter (feet) with flow at riffle cross-section (NSO #56-1) in the Lower Canyon Reach of the Crooked River downstream of the NUID Pumping plant.**
Source: Huang (2012)

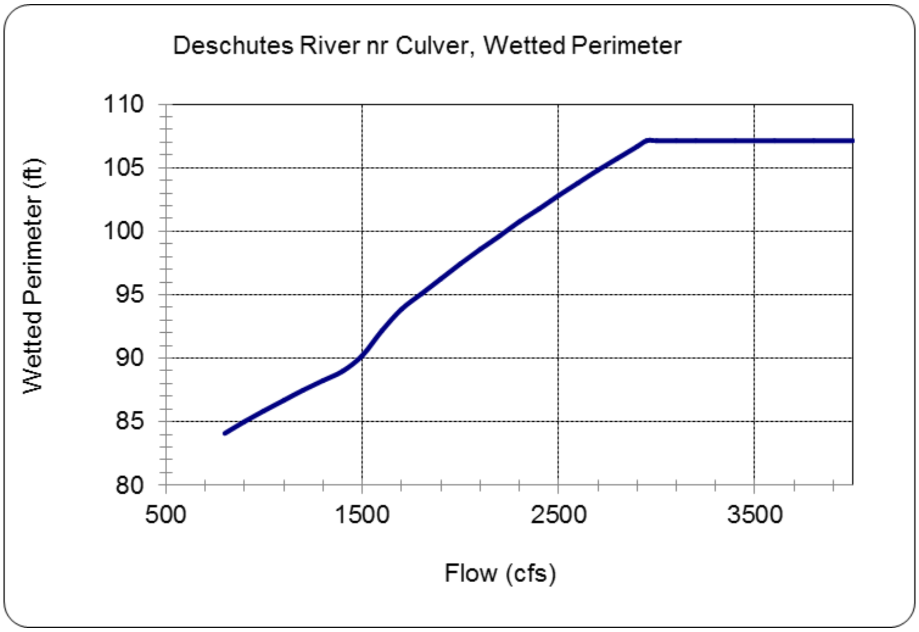


Figure 2-31. Incremental change in wetted perimeter (feet) with flow at rating curve transect 1 in the Deschutes River nr Culver, OR.
Source: Huang (2012**)**

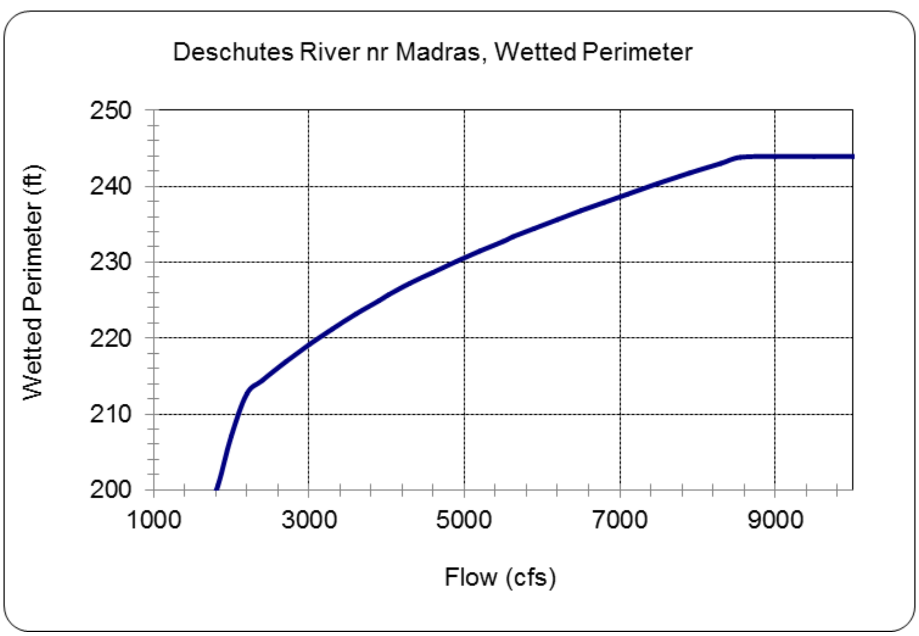


Figure 2-32. Incremental change in wetted perimeter (feet) with flow at rating curve transect 1 in the Deschutes River nr Madras, OR.
Source: Huang (2012**)**

Crooked River –Upper Canyon: On average, where the channel inflection points are obvious, the 12 riffle transects measured in the Upper Canyon reach suggest the upper inflection point is near 70 cfs, whereas the lower inflection point is near 25 cfs. As an example of food production and riffle channel shape, according to the Leathe and Nelson (1986), river flows above 70 cfs support good levels of food production, flows between 25 and 70 cfs are important for food production, and flows below 25 cfs offer rapidly declining food production (Figure 2-27).

Crooked River – Prineville Valley: On average, where the channel inflection points are obvious, the ten transects measured in the Prineville Valley reach suggest the upper inflection point is near 100 cfs, whereas the lower inflection point is near 45 cfs. According to the Leathe and Nelson (1986), river flows above 100 cfs support good levels of food production, flows between 45 and 100 cfs are important for food production, and flows below 45 cfs offer rapidly declining food production.

Crooked River – Lower Canyon: On average, where the channel inflection points are obvious, the six riffle transects measured in the lower canyon reach suggest the lower and upper inflection points are similar but occurred at a slightly lower flow level than in the Prineville Valley reach. The upper inflection point is near 80 cfs, whereas the lower inflection point is near 35 cfs.

Deschutes River – NR Culver, OR: On average, where the channel inflection points are obvious, the three transects measured near the USGS gage near Culver suggest the lower inflection point is near 1,700 cfs while the upper inflection point appears to occur at 2,950 cfs.

Deschutes River – NR Madras, OR: On average, where the channel inflection points are obvious, the three transects measured near the USGS gage near Madras indicate the lower inflection point is near 2,200 cfs while the upper inflection point appears to occur at 8,300 cfs. There are interim inflection points in the wetted perimeter curve at 3,800 and 5,500 cfs as well.

The wetter perimeter data for the USGS rating curve transects in the Deschutes River are shown for reference. These sites are good for measuring river flow, but they do not likely represent riffle habitats. Care should be exercised in the use, since these rating curve transects may provide a somewhat different result than other habitat types.

2.4.2. Toe-Width Method

The toe-width, or the distance from the toe of one streambank to the toe of the other streambank across the stream channel, has been found to have a high correlation with stream flows necessary to protect spawning and rearing habitat. The toe-width method (Swift 1976, 1979) was developed in the state of Washington and produces a strong correlation between an easily measured stream variable (the toe-width) and the empirically determined discharge that produces maximum and sustained spawning and rearing habitat for various life history stages of salmonid fish species using habitat suitability index (HSI) data.

The original toe-width methods did not have spawning and rearing relationships established for bull trout. However, the Washington State Department of Ecology (Ecology 2009) recently updated the toe-width regression curves with more recent HSI curves and defined relationships found in a set of streams and rivers across the state with both toe-width measurements and IFIM/PHABSIM study results. Ecology provides toe-width curves for native char, cutthroat, rainbow, and brook trout, and steelhead trout, coho and Chinook salmon. Ecology's available regression curves for spawning and rearing life stages for most of the covered fish species are provided in Appendix C.

Ecology compared toe-width measurements to the discharge (Q) providing the greatest weighted usable habitat area (WUA), as determined by PHABSIM studies conducted in conditions similar to the Deschutes River in western and eastern Washington (N = 17 study sites). Regression analyses were performed to determine the strength of relationship between the toe-width result (in feet) to optimal flow (in cfs) using power functions. The results were strong for salmonid fish spawners with regression coefficients of r^2 between 0.84 and 0.98 (Appendix C). An example regression is shown for steelhead trout spawning in Figure 2-33.

Although based on a relatively simply channel hydraulic metric, the toe-width method provides estimates of flow levels preferred by various fish species for spawning are rearing conditions as distributed across the year in accordance with life history stage occurrence and seasonal periodicity. Ecology's (2009) toe-width approach for spawning and rearing habitat is based on a regression analysis of toe widths and flows based on species-specific habitat suitability index (HSI) curves used in IFIM/PHABSIM studies. One of the benefits to Ecology's approach compared to prior methods is they updated HSI criteria relative to current knowledge about the species use of habitat conditions.

Unless the channel hydraulics change by means of altered flood magnitudes and return interval frequencies, the horizontal distance between the toes of the channel banks is generally a fixed increment. As a result, unlike IFIM or the wetted perimeter approach, the toe-width regression method is not an incremental technique and modifications of low flow regimes based on various DBHCP scenarios cannot be directly tested. Nevertheless, the DBHCP could use this method in their assessment by comparing the flows from different operating scenarios with the habitat flows estimated by the toe-width method. Convergence or divergence from flow levels recommended under the toe-width method could provide a relative change in habitat features in assessing impacts and for comparing the conservation measures.

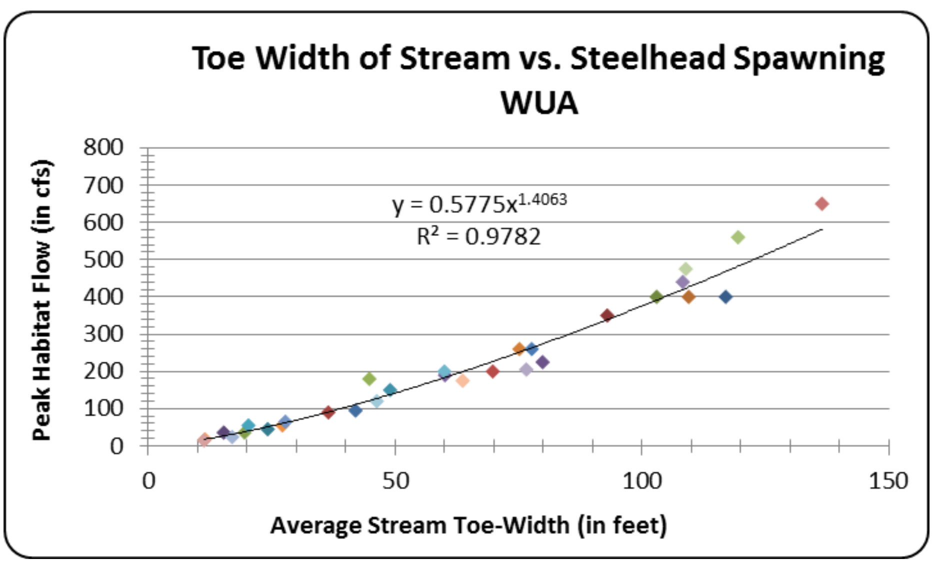


Figure 2-33. Regression equation for toe-width of stream versus peak WUA of steelhead trout spawning.
Source: Ecology (2009)

2.4.2.1. Biological Surrogate

The biological factors tied to the hydraulic channel toe-width metric are relatively strong. Nehring (1979) presented data showing a strong correlation ($r^2 = 0.92$) between stream width and standing crop (biomass) of trout. Fish production models for steelhead trout and Chinook salmon in the Deschutes River Basin using UCM, HABRATE, etc. use stream width as a critical value in estimates of available rearing space and growth parameters (Ackerman et al. 2007; Burke et al. 2010; Courter 2011; Spateholts 2012). Thus, Ecology's Toe-Width/WUA regression should provide a good level of support for assessing the biological rationale of fish habitat versus river flow changes under the DBHCP.

Since the methods have been developed by state and federal resource agencies from data collected in the Pacific Northwest from rivers the size of the Deschutes River and its tributaries, the approach should be applicable to the study reaches. The toe-width/regression method is intrinsically tied to biological parameters including fish species HSI criteria for flow-related attributes.

The biological rationale offers a direct link to preferred habitat conditions with discharge levels. However, the method is not incremental, and it does not offer an estimate of species abundance, juvenile productivity, or any other VSP parameter. Satisfying the indicated preference for hydraulic variables such as depth and velocity may have no effect on the number of fish that can be supported in a stream.

2.4.2.2. Site-specific Application – Example Reaches

Results of Ecology's recent modifications to the toe-width method (Ecology 2009) are provided in six example reaches using riffle cross-sections in Appendix D. Since the toe-width spawning and rearing regression equations are species- and life stage-specific, a monthly species prioritization has been assumed (Table 2-7). The life history stage with the highest flow need per month is selected for this comparison. Steelhead spawning and rearing life history stages were sufficient for coverage of all other covered fish species life stages. The results for the various reaches vary monthly in accordance with the different regression equations for each of the life stages and the average toe-of-the-bank measurements at available cross-sections in the reaches.

Table 2-7. Seasonal species and life-history stage priority for application of the Toe-Width-WUA Regression Method.

Month	Species and Life-History Stage Priority
January	Steelhead Rearing
Feb 01-14	Steelhead Rearing
Feb 15- 28	Steelhead Spawning
March	Steelhead Spawning
April	Steelhead Spawning
May	Steelhead Spawning
June	Steelhead Rearing
July	Steelhead Rearing
August	Steelhead Rearing
September	Steelhead Rearing
October	Steelhead Rearing
November	Steelhead Rearing
December	Steelhead Rearing

Deschutes River – Big Falls to Lake Billy Chinook: Where the toe-width measurements were clearly defined, the three riffle transects measured near Culver suggest an average toe-width of 67 feet.

Deschutes River – Downstream of Pelton Reregulating Dam: Where the toe-width measurements were clearly defined, the 28 riffle transects measured in the upper canyon reach suggest an average toe-width of 79 feet

Crooked River – Upper Canyon: Where the toe-width measurements were clearly defined, the 12 riffle transects measured in the upper canyon reach suggest an average toe-width of 62 feet.

Crooked River – Prineville Valley: Where the toe-width measurements were clearly defined, the three riffle transects measured in the valley reach suggest an average toe-width of 37 feet.

Crooked River – Lower Canyon: Where the toe-width measurements were clearly defined, the six riffle transects measured in the lower canyon reach suggest an average toe-width of 75 feet.

Ochoco Creek: Where the toe-width measurements were clearly defined, the riffle transect measured near the Breese Diversion structure suggest a toe-width of 11 feet.

Whychus Creek: Where the toe-width measurements were clearly defined, the three transects measured near the USGS stream flow gage suggest a toe-width of 12.5 feet.

The steelhead spawning and rearing regression curves included in Appendix D can be used to show effects and anticipated changes in monthly flow levels for riffle habitats with changes in river flows under various DBHCP conservation measures at these example reaches. Differences in river flows under the various scenarios can be estimated using hydrologic models such as MODSIM or the Main Model in the lower Crooked River to be determined under Study 13. A relative comparison of flows between the DBHCP scenarios with respect to the toe-width regression curves is recommended.

3.0 Recommendations

The following recommendations for Phase 2 instream flow study planning are provided below.

3.1. Assessment Tool Recommendations

Instream flow data collection efforts have occurred at four of nine reaches where DBHCP covered activities coincide with the presence or potential presence of covered fish species. Three of these reaches occur in the mainstem of the Crooked River, where IFIM/PHABSIM studies have been performed. One reach occurs in the mainstem Deschutes River downstream of the Pelton Reregulating Dam, where cross sectional transects have been used to monitor wetted perimeters for estimating changes in available spawning and rearing areas with changing river flows. Review of the IFIM data and other information available at the reaches regarding sufficiency for assessing effects and habitat changes associated with DBHCP conservation measures indicates the following:

- IFIM data for the Upper Canyon reach of the Crooked River are sufficient for use in the DBHCP. The data summary indicates there exist a complete set of three flow measurements, habitat mapping, sufficient numbers of transects measured to represent the frequency of available habitats, river velocities measured at the middle calibration flow, and a good extrapolation range for model simulation between 10 and 400 cfs.
- Limited IFIM data sets are available for the Prineville Valley and the Lower Canyon reaches of the Crooked River, with only two measurements of river discharge, and river velocities measured at the lowest calibration flow. This limitation means the extrapolation of the model simulation is restricted to the reported flow range between 10 and 140 cfs. As shown in the WUA vs. flow graphs (Figures 2-23 to 2-26), the habitat relationships for spawning and rearing juvenile fishes are not well-defined within the available simulation range. The habitat vs. discharge relationships developed by Hardin for the Lower Canyon reach are sufficient for DBHCP purposes, when the scenarios to be tested fall within the flow simulation range of less than 140 cfs. Since the difference between regulated and unregulated flows in this reach exceeds 140 cfs between February and June annually, it is likely additional transect and flow level measurements will be needed to bring this information to a level appropriate for adequate impact assessment.
- We have less confidence in the results of the Prineville Valley reach compared to the Lower Canyon reach. In addition to the limitation noted above, the Valley reach has a restricted number of transects, is lacking habitat mapping tied specifically to the individual transects, and water surface elevations (WSEs) at the transects were not reported. The WUA vs. discharge relationships developed by Hardin for the Prineville Valley reach are likely not sufficient for DBHCP purposes.
- Confidence in the existing instream flow model for the Prineville Valley and Lower Canyon reaches could be improved with further field data collection related to additional transects and a wider range of measured water surface elevations and velocity profiles compared to the original IFIM study effort.

- Consideration should be given to collecting additional transect and flow calibration data in the Crooked River-Prineville Valley and Lower Canyon reaches, as well as in establishing habitat versus flow studies using IFIM techniques in all other reaches with instream flow data gaps to improve the predictability of addressing WUA habitat changes with DBHCP incremental changes in streamflow. Reaches with instream flow data gaps as described in Section 2.3 *Data Gaps* are shown in Table 3-1. IFIM is specifically designed to compare incremental changes in indices of fish habitat with different flow scenarios.

Table 3-1. Stream reaches with instream flow data gaps.

No.	River Basin	Stream	Stream Reach	River Mile	Priority
1	Deschutes	Deschutes River	Big Falls to Lake Billy Chinook	132 - 120	
3	Deschutes	Whychus Creek	Plainview Ditch to Mouth	25.8 - 0.0	1/
5	Crooked	Crooked River	CRK R. Diversion to NUID Pumps	57.0 - 27.6	1/
6	Crooked	Crooked River	NUID Pumps to Hwy 97	27.6 - 18.0	1/
7	Crooked	Ochoco Creek	Ochoco Dam to Mouth	10.5 - 0.0	1/
8	Crooked	McKay Creek	Jones Dam to Mouth	5.3 - 0.0	1/
9	Crooked	Lytle Creek	Ochoco Main Canal to Mouth	4.0 - 0.0	

1/ Key reaches for future DBHCP study focus discussed in Section 3.2 *Reach Prioritization Recommendations*

- Alternative methods are available to describe the habitat versus flow relationship including hydrologic, hydraulic, and biological approaches that could be used to address surrogate indices of flow-related impacts, to fill data gaps, and perhaps to address low priority reaches. Of these techniques, the wetted perimeter (Nelson 1980) and toe-width/WUA regression methodology (Ecology 2009) offer the most likely acceptable approaches. Both methods have advantages and disadvantages. The wetted perimeter method offers an incremental approach related to habitat versus stream discharge for the DBHCP evaluation of effects and conservation measures, whereas the Toe-width is a fixed hydraulic measurement that does not necessarily vary with flow. On the other hand, the toe-width approach offers greater associations with a biological rationale than the wetted perimeter. At this point, when considering alternative study methods, we recommend the DBHCP use the wetted perimeter approach to provide enhanced resolution of the habitat/discharge relationship compared to the toe-width methodology. Each of these methods should be reviewed with the Working Group to assess the ability and acceptability of the various approaches.

3.2 Reach Prioritization Recommendations

Since groundwater infusion dampens the influence of modified river flows resulting from the upstream covered activities of storage, release, and in-river diversions, the Deschutes River reach downstream of Big Falls (RM 132) and the Crooked River downstream of Hwy 97 (RM 18) are not influenced in the same fashion as other reaches. Similarly, the primary management strategy for fish species in these reaches focuses on resident redband trout and not the covered fish species. As such, these reaches are not necessarily a key focus for the DBHCP.

The thermal and flow effects in the lower Deschutes River of the storage, release, and diversion of water upstream of the Pelton Round Butte Project are tempered by the groundwater flow above Lake Billy Chinook and operation of the Pelton Round Butte Project. As such, the Lower Deschutes River reach downstream of RM 100 is not influenced to the same degree as other reaches. As a result this reach is not a key focus for the DBHCP.

Conversely, given the high value of habitat for covered fish species and the reduced production potential due to low instream flow levels as a result of TSID's irrigation diversions, Whychus Creek is a key focus for the DBHCP.

The Crooked River between RM 70.5 and 57.0 is only influenced by the storage and release of water from Prineville Reservoir. There are no diversions of water in this reach, so river flows are consistent from Bowman Dam downstream to the Crooked River Diversion. The primary management strategy for fish species in this reach focuses on resident redband trout and not necessarily the covered fish species. As such, this reach is important, but it is not regarded a key focus for the DBHCP.

Given the high value of habitat for the covered fish species and the reduced production potential due to low instream flow levels as a result of irrigation diversions, the Prineville Valley and the Lower Canyon reaches of the Crooked River are a key focus for the DBHCP.

Without irrigation storage, spills and returns, it is likely lower Ochoco Creek would naturally dry on occasion during the summer months resulting in a reduced level of habitat for fish production compared to existing conditions. Nevertheless, covered fish species historically used the habitat in Ochoco Creek on a seasonal basis. Since stream flows are directly influenced by storage, releases, and a series of instream diversions and since anadromous fish restoration is important in this segment, this reach of Ochoco Creek between Ochoco dam and the creek's confluence with the Crooked River is a key focus for the DBHCP.

Without irrigation spills and returns, the lower reach of McKay Creek would naturally dry annually during the summer months of most years resulting in a reduced level of habitat for fish production compared to existing conditions. Nevertheless, covered fish species could use the habitat seasonally. With existing year-round flow, some of the highest densities of juvenile steelhead trout have been recorded in McKay Creek downstream of RM 3.3 following the release of steelhead fry in 2008 (Quesada et al. 2012). Since stream flows are directly influenced by storage, releases, and a series of instream diversions and since anadromous fish restoration is important in this segment, the reach of McKay Creek between Jones Dam and its confluence with the Crooked River is a key focus for the DBHCP.

Without irrigation spills and returns, Lytle Creek would naturally dry annually during the summer months of most years resulting in a lack of habitat for fish production. Whereas covered fish species could use the habitat seasonally, it is not regarded as central for restoration of anadromy in the upper Deschutes River basin. As such, this reach is not a key focus for the DBHCP.

We recommend the DBHCP consider as top priority the following key reaches in moving forward with an instream flow evaluation of effects and conservation measures. We recommend performing IFIM or wetted perimeter assessments, or some combination of both methods, to fill the instream flow data gaps:

- Whychus Creek – TSID diversion dam to the mouth of Whychus Creek; especially key reach segments between the diversion dam and the city of Sisters (RM 20 – 24) and near Camp Polk Meadows between RM 16.0 and RM 17.5.
- Crooked River – Prineville Valley Reach; Crooked River Diversion to NUID Pumps; especially key reach segments for habitat quality near RM 43 and for upstream fish migration between RM 34 and RM 46 and between RM 48 and RM 51.
- Crooked River – Lower Canyon; NUID Pumps to Highway 97; focusing on reducing water temperatures throughout this entire area without any specifically identified key subreach segments.
- Ochoco Creek – Ochoco Dam to the mouth of Ochoco Creek with key habitat segments between the Dam and Red Granary Diversion (RM 10.4 to RM 11.1) and between the Crooked River Distribution Canal spill and Ryegrass Diversion (RM 4.7 to RM 5.1) and a key covered activities effects segment between RM 5.1 and RM 10.4 that includes the Red Granary and Breese diversions and multiple patron pumps.
- McKay Creek – Jones Dam to the mouth of McKay Creek; especially for fish habitat downstream of Grimes Road at Reynolds (RM 3.3) and the lowermost mile in the creek, downstream of RM 1.0 and a key covered activities effect segment between RM 3.2 and RM 5.8 that includes the influence of the Jones diversion prior to the Reynolds spill.

4.0 References

Ackerman, N. K., C. Justice, and S. Cramer. 2007. Juvenile steelhead carrying capacity of the upper Deschutes Basin 2007 update. Report prepared by Cramer Fish Sciences for Portland General Electric Company, Portland, Oregon.

Biota Pacific, Inc., R2 Resource Consultants, Inc., and Newton Consultants, Inc. (Biota Pacific et al.). 2011. Assessment of potential gaps in data needed to include steelhead and bull trout as covered species in the Deschutes Basin Multi-species Habitat Conservation Plan. Report prepared for the Deschutes Basin Board of Control and the City of Prineville, OR. August 2011. 110p.

Bovee, K.D. 1982. A guide to stream habitat analysis using the Instream Flow Incremental Methodology. Instream Flow Information Paper No. 12. FWS/OBS-82/26. Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service, Fort Collins, Colorado. 249p.

Burke, J. L., K. K. Jones, and J. M. Dambacher. 2003. HabRate: A stream habitat evaluation methodology for assessing potential production of salmon and steelhead in the Middle Deschutes River Basin. Draft Report by Oregon Department of Fish & Wildlife, Portland, OR. July 23.

Burke, J.L., K. K. Jones, and J.M. Dambacher. 2010. Habrate: A limiting factors model for assessing stream habitat quality for salmon and steelhead in the Deschutes River Basin. Information Report 2010-03, Oregon Department of Fish and Wildlife, Corvallis, OR. 31p. + app.

Bureau of Land Management, U.S. Forest Service, and the Oregon State Parks and Recreation Department (BLM et al.). 1992. Middle Deschutes/Lower Crooked River and Scenic Rivers' Management Plan. BLM-OR-PT-93-11-1792. December, 1992. 66p + app.

Courter, I. 2011. Utility of the Crooked River Steelhead Life-Cycle Model for predicting probability of successful steelhead reintroduction. Technical Memorandum to Julie Keil, Portland General Electric, Portland, OR by Ian Courter, Cramer Fish Sciences, Gresham, OR. January 28, 2011. 19p.

Fies, T., J. Fortune, B. Lewis, M. Manion, S. Marx. 1996. Upper Deschutes River Subbasin Fish Management Plan. Oregon Department of Fish & Wildlife. Upper Deschutes Fish District.

Gannett, M. and K. Lite Jr. 2004. Simulation of regional groundwater flow in the Upper Deschutes Basin, Oregon. U.S. Geological Survey, Water Resources Investigations Report 03-4195.

Gannett, M., K. Lite Jr., D. Morgan and C. Collins. 2001. Ground-water hydrology of the Upper Deschutes Basin, Oregon. U.S. Department of Interior U.S. Geological Survey. Water Resources Investigations Report 00-4162.

Gannett, M., M. Manga, and K. Lite Jr. 2002. Groundwater hydrology of the Upper Deschutes Basin and its influence on stream flow. Abstracts from the Deschutes Basin Groundwater Study, Oregon Water Science Center. U.S. Geological Society, Portland, Oregon.

Gippel, C. J. and M. J. Stewardson. 1998. Use of wetted perimeter in defining minimum environmental flows. Regulated Rivers: Research and Management, 14: 53–67. Cooperative Research Centre for Catchment Hydrology, Department of Civil and Environmental Engineering, The University of Melbourne, Parkville, Australia.

Hardin, T. 1993. Crooked River Instream Flow Study. Prepared for ODFW, BLM, and BOR. ODFW, Bend Office by Hardin-Davis, Inc. Albany, OR. 18p. +app. June.

Hardin, T. 2001. Physical Habitat for anadromous species in the Crooked River below Bowman Dam. Report prepared for BOR, Boise, ID by Hardin-Davis, Inc. Corvallis, OR, 4p. + tables, figures and app.

Hosman, K.J., L.L. Ely, and J.E. O'Connor. 2003. Holocene paleoflood hydrology of the Lower Deschutes River, Oregon. Pages 121-146 *In* J.E. O'Connor and G.E. Grant, Editors. A Peculiar River: Geology, Geomorphology, and Hydrology of the Deschutes River, Oregon. Water Science and Application 7. American Geophysical Union. Washington, DC.

Houston, R. 2012. Personal communication of Ryan Houston, Executive Direction of the Upper Deschutes Watershed Council, with R. Campbell, R2 Resource Consultants, Inc. by telephone on October 16, 2012.

Huang, C. 2012. Personal communication, email from Chiming Huang, R2 Resource Consultants, Inc. to Ron Campbell, R2 Resource Consultants dated August 24, 2012 regarding Hardin (1993) cross section and hydraulic data analysis.

Huntington, C.W. 1985. Deschutes River spawning gravel study. Buell and Associates, Inc. for the Bonneville Power Administration. BPA Project No. 83-423. Bonneville Power Administration. Portland, Oregon.

Huntington, C., T. Hardin, and R. Raymond. 1999. Water temperatures in the Lower Deschutes River, Oregon. Portland General Electric Company. Portland, Oregon.

LaMarche, J. 2007. Results from 2007 Crooked River Seepage Run. OWRD technical memorandum from Jonathan LaMarche, hydrologist, to K. Gorman, South Central Region Manager dated 2 January 2007 [*but in reality it was 2008 since the work was conducted in October 2007*].

Lauman, J. and W. Pitney. 1973. Fish and wildlife resources of the Deschutes River Basin and their water requirements. The Oregon Game Commission.

Leathe, S.A., and Nelson, F.A. 1986. A literature evaluation of Montana's wetted perimeter inflection point method for deriving instream flow recommendations: Department of Fish, Wildlife, and Parks, Helena, MT. 70 p.

Marx, S. 2003. Anadromous fish and bull trout management in the Upper Deschutes, Crooked, and Metolius River Subbasins. Oregon Department of Fish & Wildlife. Salem, Oregon.

McSwain, M. 1999. Personal communication with M. McSwain of the Bureau of Land Management: Prineville, Oregon as report _in_: Whitman (2002).

Moore, K. M. S., K. K. Jones and J. M. Dambacher. 1997. Methods for Stream Habitat Surveys. Information Report 97-4. Portland. Oregon Department of Fish and Wildlife. 31p. + App.

National Marine Fisheries Service (NMFS). 2005. Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act consultation for the ongoing operation and maintenance of the Deschutes River Basin Projects; Deschutes River, Crooked River and Clear Creek; Crook Deschutes, Jefferson, and Wasco Counties, Oregon. 17070306 (Lower Deschutes), 17070301 (upper Deschutes), 17070305 (Lower Crooked). For the U.S. Bureau of Reclamation, Pacific Northwest Region. February 17, 2005 69p. as amended August 30, 2005 3p.

National Resources Conservation Service (NRCS). 2010. Preliminary hydraulic analysis and restoration recommendations for the Lower Crooked River, Prineville to Lone Pine. Report submitted to the Crooked River Watershed Council by USDS NRCS, Portland, OR. February 2010, 64p.

Nehring, R.B. 1979. Evaluation of instream flow methods and determination of water quantity needs for streams in the State of Colorado. Colorado Division of Wildlife. Fort Collins, CO. 144 p.

Nelson, F.A. 1980. Evaluation of selected instream flow methods in Montana. Proceedings of the Annual Conference of the Western Association of Fish and Wildlife Agencies: 412 – 432. This paper was based on a report to the U.S. Fish and Wildlife Service prepared by the Montana Department of Fish, Wildlife and Parks, Bozeman, Montana.

Nesbit, S.M. 2010. Population characteristics and movement patterns of redband trout (*Oncorhynchus mykiss*) and mountain whitefish (*Prosopium williamsoni*) in the Crooked River, Oregon. M.S. Thesis in Fisheries Science presented on June 4, 2010, Oregon State University, Corvallis, OR.

Nielsen-Pincus, M. (ed.) 2008. Lower Crooked River Watershed Assessment. Crooked River Watershed Council. Prineville, OR. February, 2008. 227p.

Northwest Power and Conservation Council (NPCC). 2004. Final Deschutes Subbasin Plan. The Deschutes Coordinating Group (DCG), Northwest Power and Conservation Council, Portland OR. 668p. May.

Oregon Department of Environmental Quality (ODEQ). 2002. CWA §401 Water Quality Certification Conditions for the Pelton Round Butte Project; FERC #2030. Hydropower Certification prepared by ODEQ on July 8, 2002 as modified on June 25, 2003. 12p.

Oregon Department of Fish and Wildlife (ODFW). 1996. Aquatic Inventory Protocol surveys for the Deschutes River reach between Big Falls and Lake Billy Chinook.

Oregon Department of Fish and Wildlife (ODFW). 2006. Aquatic Inventory Protocol surveys for Crooked River reach between Lone Pine Bridge and Peoples Diversion.

Oregon State Game Commission (OSGC). 1956. Annual Report. Report prepared by Robert Borovicka, Oregon State Game Commission, Portland, Oregon.

Oregon Water Resources Department (OWRD). Statistical Summaries of Streamflow http://www.wrd.state.or.us Salem, Oregon.

Portland General Electric (PGE). 2001. Final Joint Application Amendment for the Pelton Round Butte Hydroelectric Project. FERC Project No. 2030. Volume 1 of 3. June 2001.

Quesada, C., M. Bennett, and M. Hill. 2012. Native Fish Monitoring: Biological Component. 2011 Annual Report and 2012 Work Plan. Portland General Electric. Portland, Oregon.

Reiser, D. W., T. A. Wesche, and C. Estes. 1989. Status of instream flow legislation and practices in North American. Fisheries. Vol. 14, No. 2, pp. 22-29.

Richter, B. D., J. V. Baumgartner, J. Powell, and D. P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. Conservation Biology 10(4): 1163-1174.

Riehle, M. 1999. Habitat quality for anadromous fish upstream of the Pelton Round Butte Hydroelectric Project. Portland General Electric Company, Portland, Oregon.

Spateholts, B. 2008. Pelton Round Butte Project (FERC 2030) Native Fish Monitoring Plan (Habitat Component) License Article 421: 2007 Annual Report and 2008 Work Plan. Portland General Electric Company. Portland, Oregon. Tab 14 in Pelton Round Butte 2008 Fisheries Workshop Binder. Portland General Electric Company.

Spateholts, B. 2012. Pelton Round Butte Project (FERC 2030) Native Fish Monitoring Plan (Habitat Component) License Article 421: 2011 Annual Report and 2012 Work Plan. Portland General Electric Company. Portland, Oregon.

Stalnaker, C., B.L. Lamb, J. Henriksen, K. Bovee, J. Bartholow. 1994. The Instream Flow Incremental Methodology: A Primer for IFIM. National Ecology Research Center, Internal Publication. National Biological Survey. Fort Collins, Colorado. 99 pp.

Stuart, A. M., S. L. Thiesfeld, T. K. Nelson, and T. M. Shrader. 1996. Crooked River Basin Plan. Ochoco Fish District. Oregon Department of Fish and Wildlife.

Swift, C.H. 1976. Estimates of stream discharges preferred by steelhead trout for spawning and rearing in western Washington. USGS Open File Report 75-155. U.S. Geological Survey, Tacoma, WA.

Swift, C.H. 1979. Preferred stream discharge by for salmon spawning and rearing in Washington. USGS Open File Report 77-422. U.S. Geological Survey, Tacoma, WA.

Stillwater Sciences. 2007. Deschutes River - lower river gravel study. 2007. Progress Report prepared by Stillwater Sciences, Berkeley, California; prepared for, Portland General Electric Company. Portland, Oregon.

Tennant, D. L. 1975. Instream flow regimens for fish, wildlife, recreation and related environmental resources. U.S. Fish and Wildlife Service, Billings, Montana. 30 p.

Tennant, D. L. 1976. Instream flow requirements for fish, wildlife, recreation, and related environmental resources. In Proc. Symposium and Specialty Conference on Instream Flow Needs (J.G. Orsborn and C.H. Allman, eds.), Vol. II, pp. 359-373. American Fisheries Society, Bethesda, MD.

Tessman, S.A. 1980. Environmental assessment, technical appendix E in environmental use sector reconnaissance elements of the western Dakotas region of South Dakota study, Brookings, SD: South Dakota State University, Water Resources Research Institute.

The Nature Conservancy. 2007. Indicators of Hydrologic Alteration. Version 7, User's Manual. The Nature Conservancy with Totten Software Design and Smythe Scientific Software. 70 pages. March.

Thompson, K. 1972. Determining stream flows for fish life. Pages 31-50 in Proceedings, Instream Flow Requirements Workshop. Pacific Northwest River Basins Commission, Vancouver, Washington.

Upper Deschutes Local Advisory Committee (UDLAC). 2003. Upper Deschutes Agricultural Water Quality Management Area Plan. Upper Deschutes Local Advisory Committee with assistance from Oregon Department of Agriculture and Deschutes Soil and Water Conservation District, Redmond, Oregon.

Upper Deschutes Watershed Council (UDWC). 2007. 2007 Annual Report; Whychus Creek Restoration Project at Camp Polk; Camp Polk Meadow Preserve (Sisters, Oregon). Joint effort of the Upper Deschutes Watershed Council and the Deschutes Basin Land Trust. 8p.

U.S. Fish and Wildlife Service (USFWS). 2010. Revised designation of critical habitat for bull trout (*Salvelinus confluentus*) in the coterminous United States; Final Rule. Federal Register 75 (200)-63898.

Walter, P. 2000. Channel habitat type, riparian and channel condition assessment for Ochoco, Mill, McKay and Marks creeks, Crooked River Basin, Oregon Master's Thesis. Department of Planning, Public Policy and Management. University of Oregon: Eugene, Oregon.

Washington State Department of Ecology (Ecology). 2009. Analysis of PHABSIM and Toe-Width; Updated toe-width equations for various spawning and rearing life stages of salmon and trout; initial results. File: Ecology_WUA-TW eval 10-09(2).xls transmitted from J. Pacheco to R2 Resource Consultants December 1, 2009.

Watershed Professional Network (WPN). 2011. Crooked River environmental flows assessment. Final summary report prepared for the Nature Conservancy and the Deschutes River Conservancy. March 18, 2011, Accessed at: http://watershednet.com/downloads/cref/

Watershed Sciences, Inc. 2006. Airborne thermal infrared remote sensing, Crooked River, OR. Prepared for Oregon Department of Environmental Quality, Portland, OR.

Watershed Sciences and MaxDepth Aquatics. 2008. Deschutes River, Whychus Creek, and Tumalo Creek Temperature Modeling. Report prepared by Watershed Sciences and MaxDepth Aquatics, Inc. of Bend, OR for the State of Oregon Department of Environmental Quality.

Whitman, T. 2002. Crooked River Watershed Assessment. Crooked River Watershed Council, Prineville, OR. July 2002, 155p + app.

Zimmerman, C.E., and G.H. Reeves. 2000. Population structure of sympatric anadromous and non-anadromous *Oncorhynchus mykiss*; evidence from spawning surveys and otolith microchemistry. Canadian Journal of Fisheries and Aquatic Sciences 57: 2152-2162.

Zimmerman, C.E. and D.E. Ratliff. 2003. Controls on the distribution and life history of fish populations in the Deschutes River: geology, hydrology, and dams. Pages 51-70 *In* J.E. O'Connor and G.E. Grant, Editors. A Peculiar River: Geology, Geomorphology, and Hydrology of the Deschutes River, Oregon. Water Science and Application 7. American Geophysical Union. Washington, DC.

Appendices

Appendix A – IFIM Study Transect Data

Table A-1. Cross sectional transects and representative habitat types measured in Crooked River segments during IFIM/PHABSIM study.
Source: Hardin (1993)

	Segment 1	Segment 2		Segment 3	
Habitat Type	Upper Canyon	Prineville Valley		Lower Canyon	Total
		Les Schwab Ball Field	Quail Valley Ranch		
Riffle	12	3	0	6	21
Glide	9	1	2	6	18
Pool	4	2	2	6	14
Pocket Water	0	0	0	7	7
Total TRs	25	6	4	25	60

Table A-2. Summary of transect data from Upper Canyon (Segment 1)
Source: Hardin (1993)

Unit #	Habitat Type	Number of Velocity Sets	Number of Q~WSE Sets	Substrate Data Available	Cover Data Available	Calibration Flows (cfs)			Simulation Q Range (cfs)	
						Q1	Q2	Q3	Q_{lowest}	$Q_{highest}$
1	Riffle	1 (V_2)	3	Yes	Yes	28	143	234	10	400
2	Riffle	1 (V_2)	3	Yes	Yes	28	143	234	10	400
3	Riffle	1 (V_2)	3	Yes	Yes	28	143	234	10	400
4	Riffle	1 (V_2)	3	Yes	Yes	28	143	234	10	400
5	Riffle	1 (V_2)	3	Yes	Yes	28	143	234	10	400
6	Riffle	1 (V_2)	3	Yes	Yes	28	143	234	10	400
7	Riffle	1 (V_2)	3	Yes	Yes	28	143	234	10	400
8	Riffle	1 (V_2)	3	Yes	Yes	28	143	234	10	400
9	Riffle	1 (V_2)	3	Yes	Yes	28	143	234	10	400
10	Riffle	1 (V_2)	3	Yes	Yes	28	143	234	10	400
11	Riffle	1 (V_2)	3	Yes	Yes	28	143	234	10	400
12	Riffle	1 (V_2)	3	Yes	Yes	28	143	234	10	400
13	Glide	1 (V_2)	3	Yes	Yes	28	143	234	10	400
14	Glide	1 (V_2)	3	Yes	Yes	28	143	234	10	400
15	Glide	1 (V_2)	3	Yes	Yes	28	143	234	10	400
16	Glide	1 (V_2)	3	Yes	Yes	28	143	234	10	400
17	Glide	1 (V_2)	3	Yes	Yes	28	143	234	10	400
18	Glide	1 (V_2)	3	Yes	Yes	28	143	234	10	400
19	Glide	1 (V_2)	3	Yes	Yes	28	143	234	10	400
20	Glide	1 (V_2)	3	Yes	Yes	28	143	234	10	400
21	Glide	1 (V_2)	3	Yes	Yes	28	143	234	10	400
22	Pool	1 (V_2)	3	Yes	Yes	28	143	234	10	400
23	Pool	1 (V_2)	3	Yes	Yes	28	143	234	10	400
24	Pool	1 (V_2)	3	Yes	Yes	28	143	234	10	400
25	Pool	1 (V_2)	3	Yes	Yes	28	143	234	10	400

Table A-3. Summary of transect data from Prineville Valley (Segment 2).
Source: Hardin (1993)

Unit #	Site	Habitat Type	Number of Velocity Sets	Number of Q~WSE Sets	Substrate Data Available	Cover Data Available	Calibration Flows (cfs)		Simulation Q Range (cfs)	
							Q1	Q2	Q_{lowest}	$Q_{highest}$
1	Les Schwab Ball Field		1 (V_1)	2	Yes	Yes	29	115	10	140
2			1 (V_1)	2	Yes	Yes	29	115	10	140
3			1 (V_1)	2	Yes	Yes	29	115	10	140
4			1 (V_1)	2	Yes	Yes	29	115	10	140
5			1 (V_1)	2	Yes	Yes	29	115	10	140
6			1 (V_1)	2	Yes	Yes	29	115	10	140
7	Quail Valley Ranch		1 (V_1)	2	Yes	Yes	29	115	10	140
8			1 (V_1)	2	Yes	Yes	29	115	10	140
9			1 (V_1)	2	Yes	Yes	29	115	10	140
10			1 (V_1)	2	Yes	Yes	29	115	10	140

Table A-4. Summary of transect data from Lower Canyon (Segment 3).
Source: Hardin (1993)

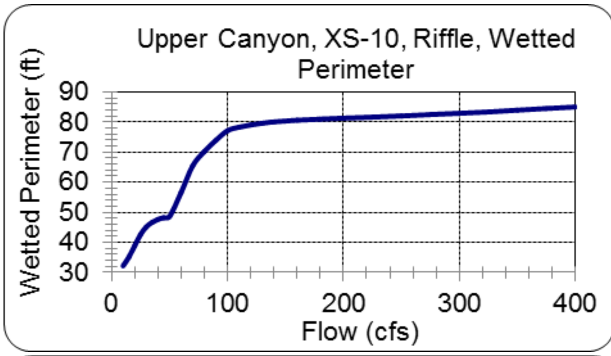
Unit #	Site	Habitat Type	Number of Velocity Sets	Number of Q~WSE Sets	Substrate Data Available	Cover Data Available	Calibration Flows (cfs)		Simulation Q Range (cfs)	
							Q1	Q2	Q_{lowest}	$Q_{highest}$
1	108	Glide	1 (V_1)	2	Yes	Yes	23	116	10	140
2	108	Glide	1 (V_1)	2	Yes	Yes	23	116	10	140
3	108	Glide	1 (V_1)	2	Yes	Yes	23	116	10	140
4	164	Glide	1 (V_1)	2	Yes	Yes	23	116	10	140
5	164	Glide	1 (V_1)	2	Yes	Yes	23	116	10	140
6	164	Glide	1 (V_1)	2	Yes	Yes	23	116	10	140
7	56	Riffle	1 (V_1)	2	Yes	Yes	30	116	10	140
8	56	Riffle	1 (V_1)	2	Yes	Yes	30	116	10	140
9	56	Riffle	1 (V_1)	2	Yes	Yes	30	116	10	140
10	58	Riffle	1 (V_1)	2	Yes	Yes	30	116	10	140
11	58	Riffle	1 (V_1)	2	Yes	Yes	30	116	10	140
12	58	Riffle	1 (V_1)	2	Yes	Yes	30	116	10	140
13	110	Pool	1 (V_1)	2	Yes	Yes	23	116	10	140
14	110	Pool	1 (V_1)	2	Yes	Yes	23	116	10	140
15	110	Pool	1 (V_1)	2	Yes	Yes	23	116	10	140
16	60	Pool	1 (V_1)	2	Yes	Yes	30	116	10	140
17	60	Pool	1 (V_1)	2	Yes	Yes	30	116	10	140
18	60	Pool	1 (V_1)	2	Yes	Yes	30	116	10	140
19	162	Pocket Water	1 (V_1)	2	Yes	Yes	23	116	10	140
20	162	Pocket Water	1 (V_1)	2	Yes	Yes	23	116	10	140
21	106	Pocket Water	1 (V_1)	2	Yes	Yes	23	116	10	140
22	106	Pocket Water	1 (V_1)	2	Yes	Yes	23	116	10	140
23	5	Pocket Water	1 (V_1)	2	Yes	Yes	17	116	10	140
24	5	Pocket Water	1 (V_1)	2	Yes	Yes	17	116	10	140
25	5	Pocket Water	1 (V_1)	2	Yes	Yes	17	116	10	140

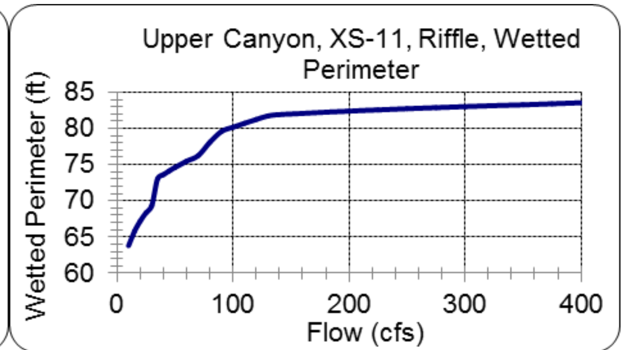
Table A-5. IFIM/PHABSIM Study Data Summary
Source: after Hardin (1993)

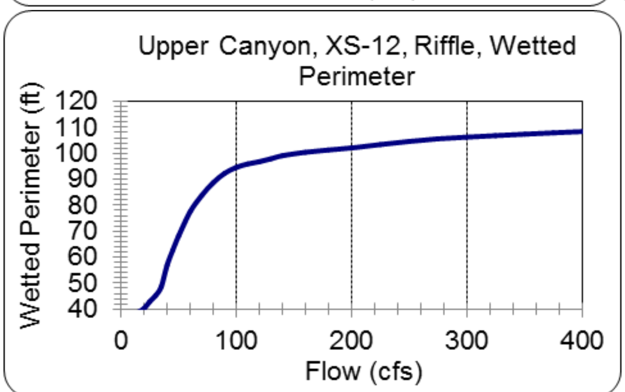
Category			Segment 1	Segment 2		Segment 3	Total
				Valley Segment			
			Upper Canyon	Les Schwab Ball Field	Quail Valley Ranch	Lower Canyon	
Stream Length			~ 12 miles	~ 31 miles		~ 10 miles	~ 53 miles
Gradient			0.2% ~ 0.3%	0.1% ~ 0.2 %		0.5% ~ 1%	-
Habitat Sampling	Number of Transects	Riffle	12	3		6	21
		Glide	9	1	2	6	18
		Pool	4	2	2	6	14
		Pocket Water				7	7
	Total # of TRs		25	6	4	25	60
	# TRs per River Mile		2.1	0.32		2.5	1.1
Habitat Mapping	Number of Units	Riffle	45	Habitat not Mapped	Habitat not Mapped	32	NA
		Glide	41			50	
		Pool	13			57	
		Pocket Water				51	
	Total Length (ft)	Riffle	18488			7600	NA
		Glide	18638			14750	
		Pool	1716			18500	
		Pocket Water				9780	
	% by Length	Riffle	47.6%			15.0%	NA
		Glide	48.0%			29.1%	
		Pool	4.4%			36.5%	
		Pocket Water				19.3%	

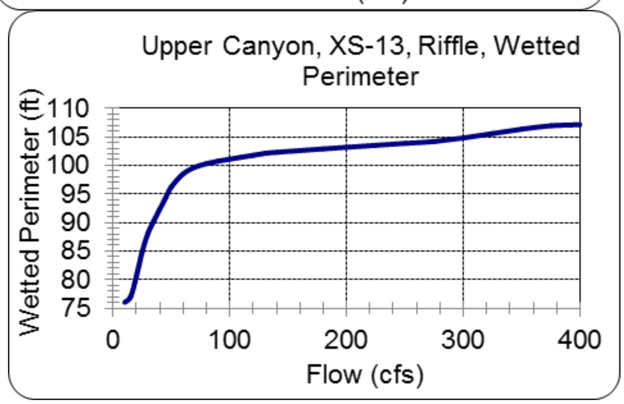
Appendix B – Wetted Perimeter Relationships at Various Reaches.

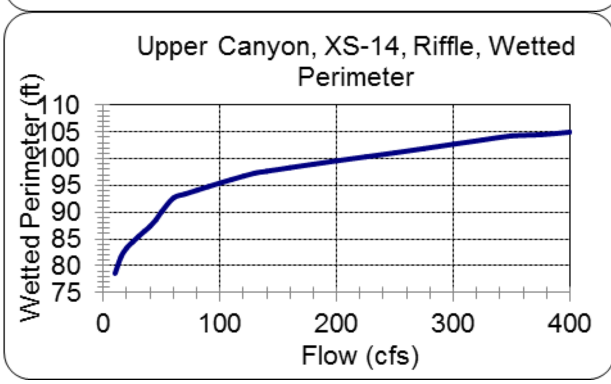
Crooked River – Upper Canyon Reach

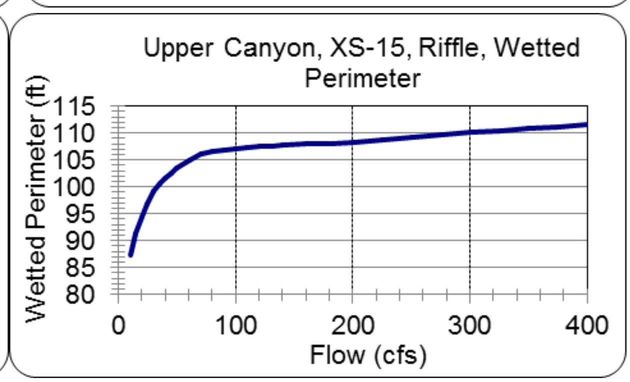


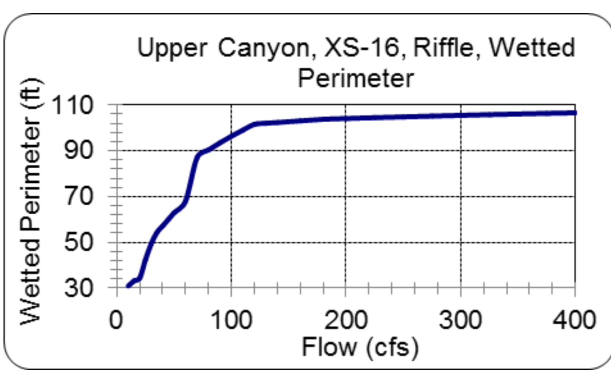


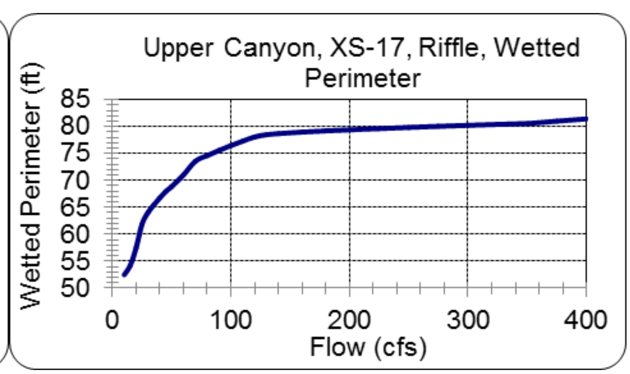


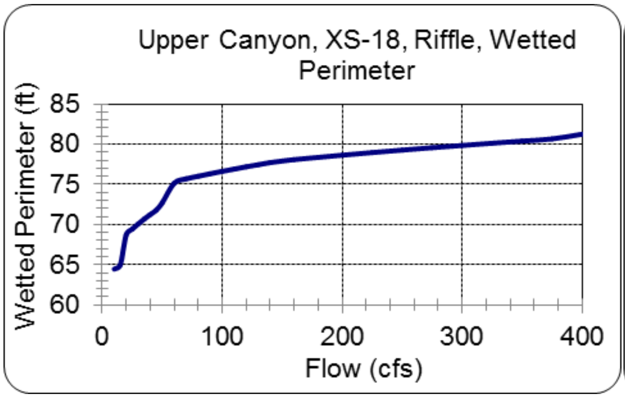


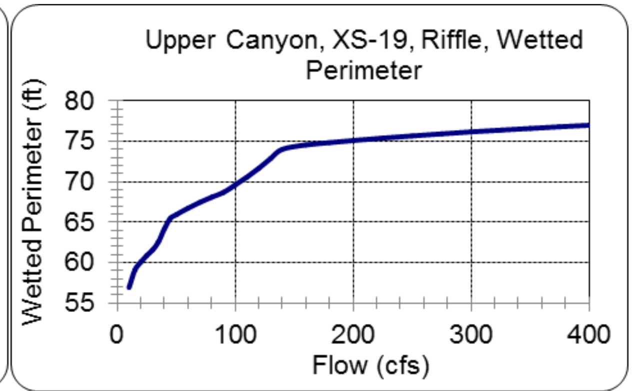


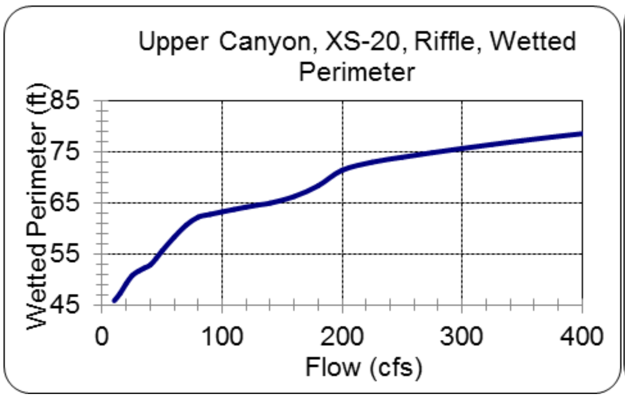


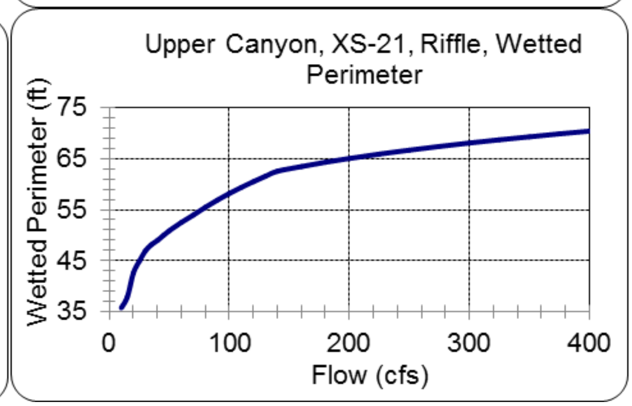




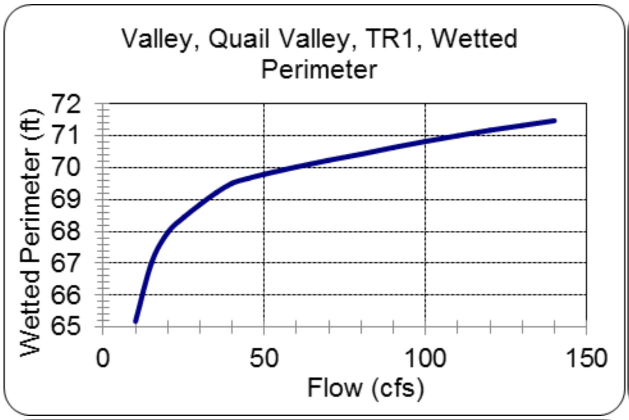

Upper Canyon, XS-18, Riffle, Wetted Perimeter
Wetted Perimeter (ft)
85
80
75
70
65
60
0
100
200
300
400
Flow (cfs)

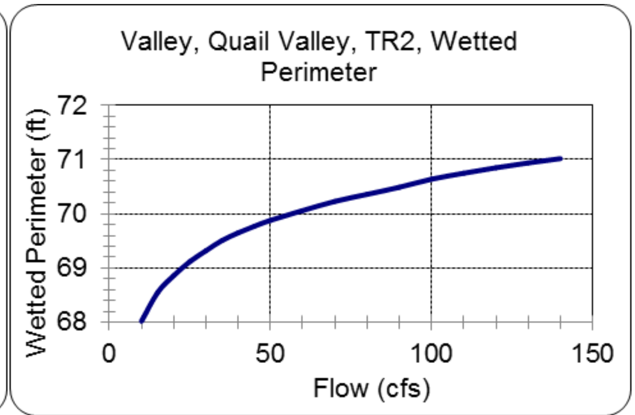

Upper Canyon, XS-19, Riffle, Wetted Perimeter
Wetted Perimeter (ft)
80
75
70
65
60
55
0
100
200
300
400
Flow (cfs)

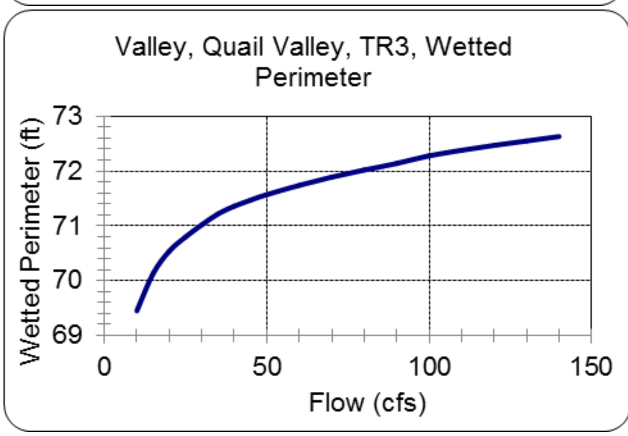

Upper Canyon, XS-20, Riffle, Wetted Perimeter
Wetted Perimeter (ft)
85
75
65
55
45
0
100
200
300
400
Flow (cfs)

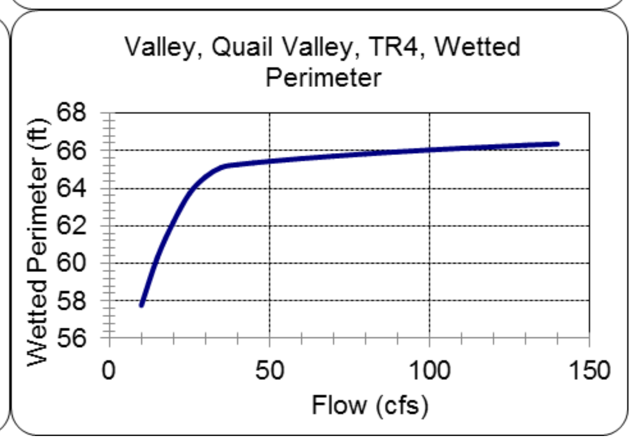

Upper Canyon, XS-21, Riffle, Wetted Perimeter
Wetted Perimeter (ft)
75
65
55
45
35
0
100
200
300
400
Flow (cfs)

Crooked River – Prineville Valley Reach: Quail Valley Transects

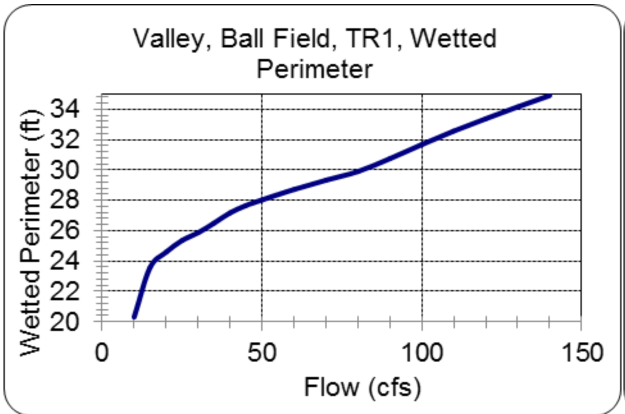


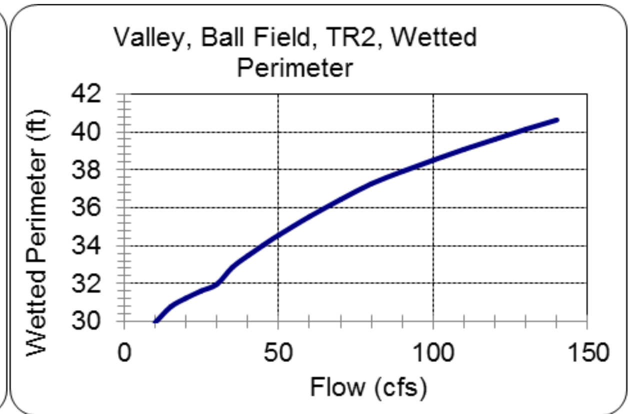


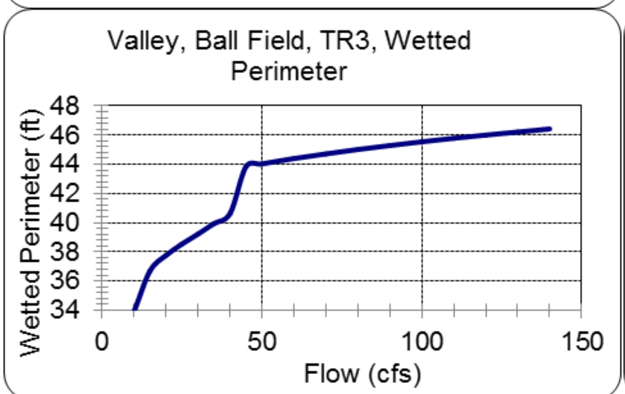


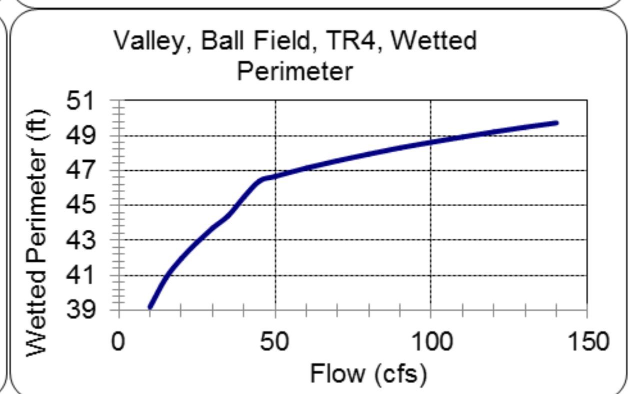


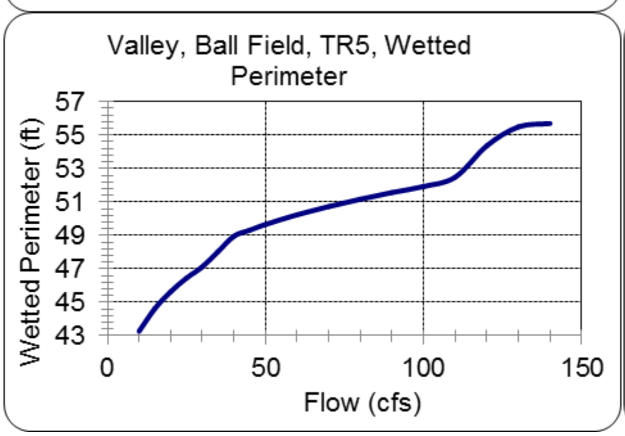
Crooked River – Prineville Valley Reach: Les Schwab Ball Field Transects

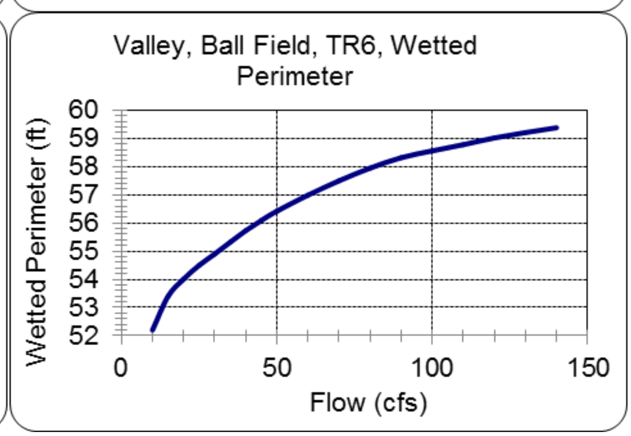




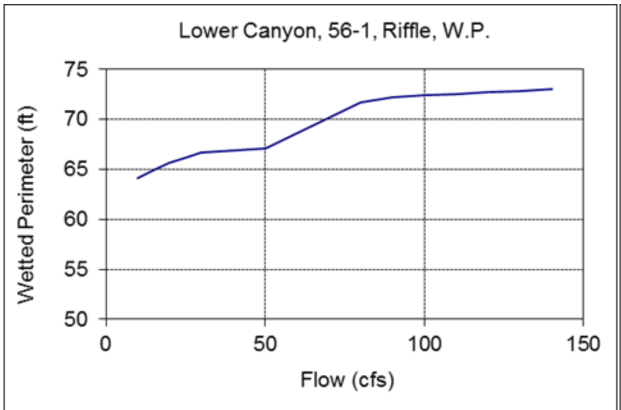


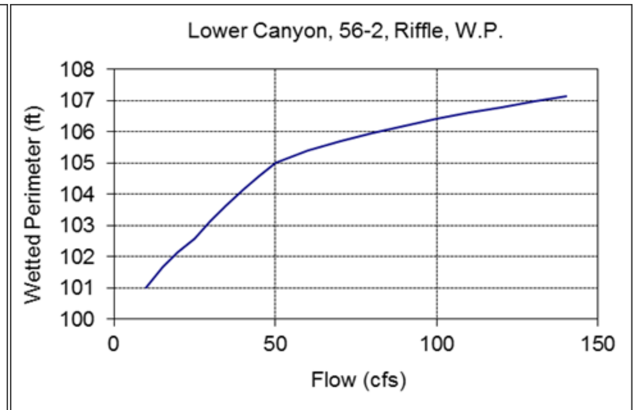


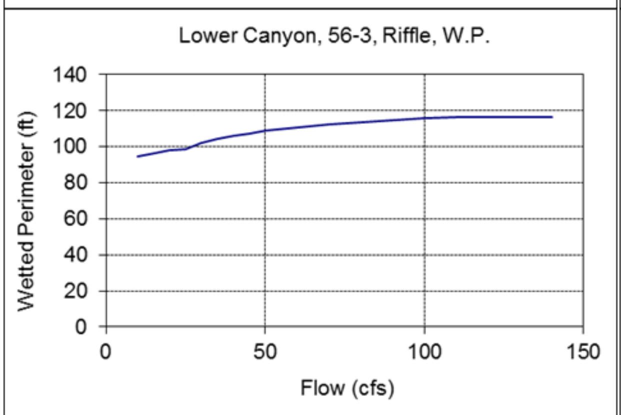


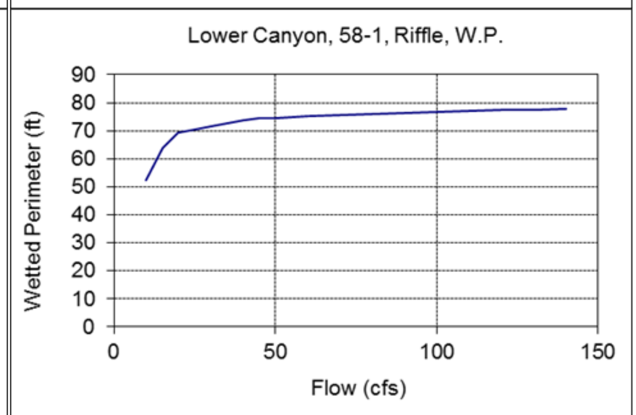


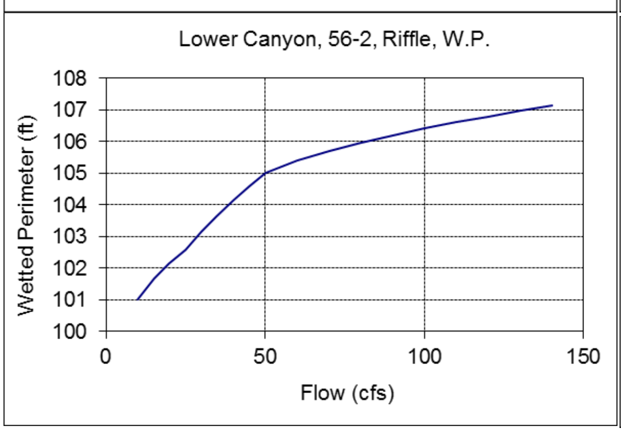
Crooked River – Lower Canyon Reach

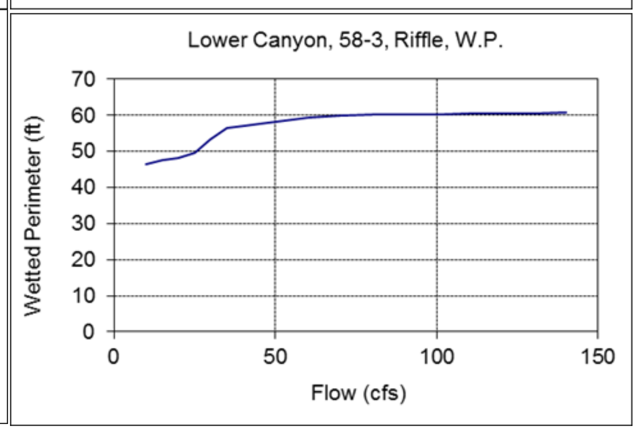




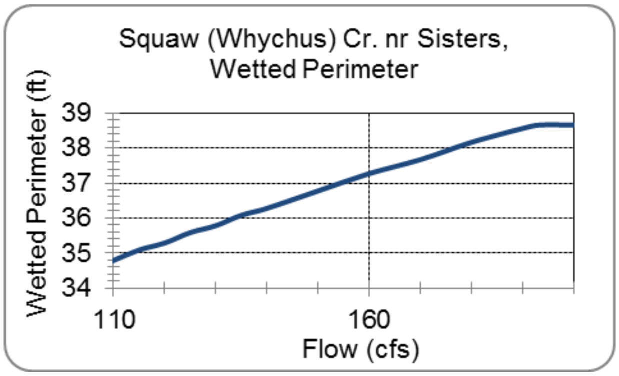




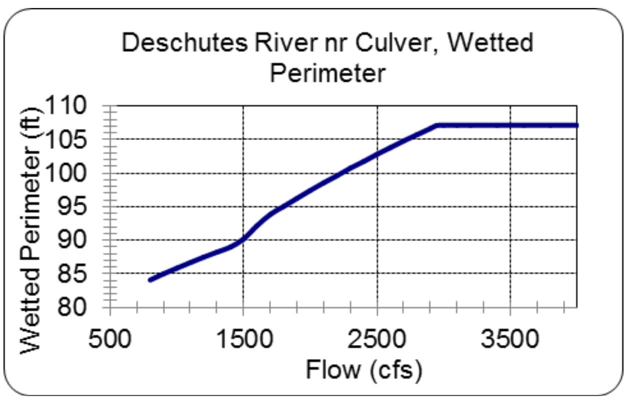


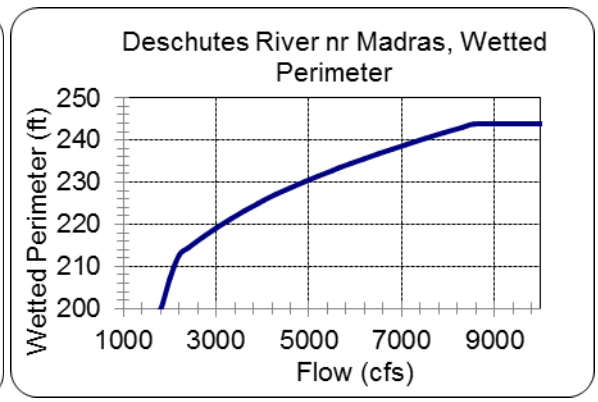


Whychus Creek– USGS Gage nr Sisters, OR Rating Curve Transect 1

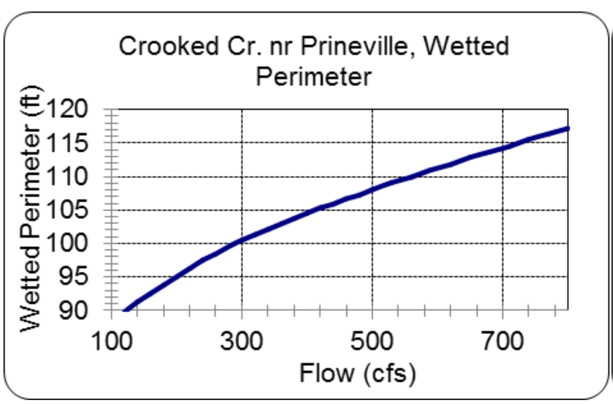


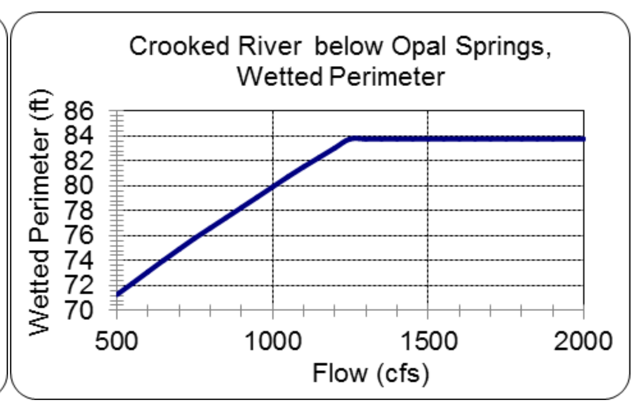
Deschutes River– USGS Gage nr Culver, and nr Madras OR Rating Curve Transect 1





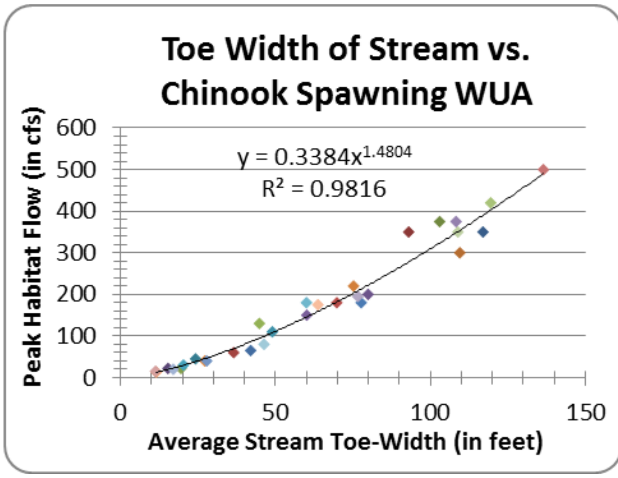
Crooked River– USGS Gage nr Prineville, and bl Opal Springs, OR Rating Transect 1

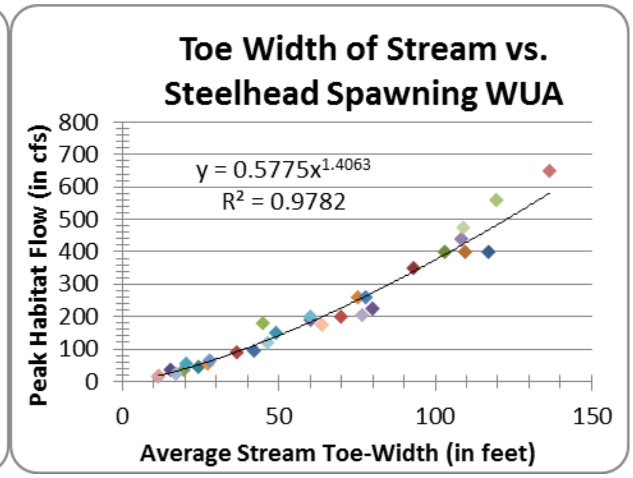




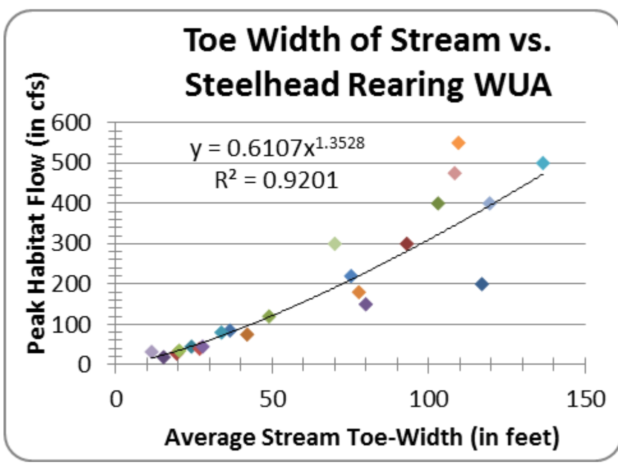
Appendix C – Washington State Department of Ecology Toe-Width Regression Curves for covered fish species.

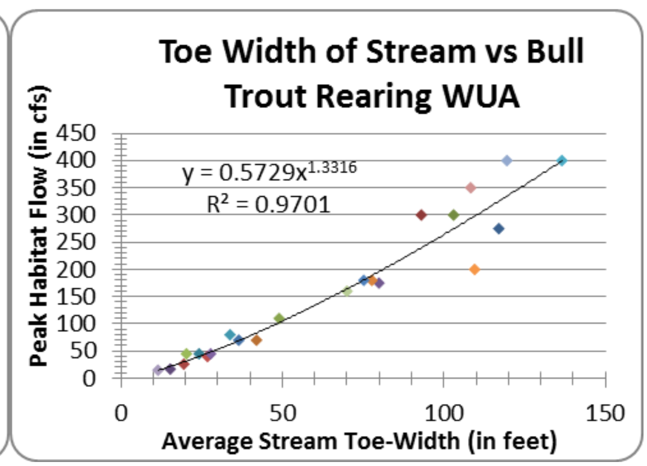
Spawning Life History Stages





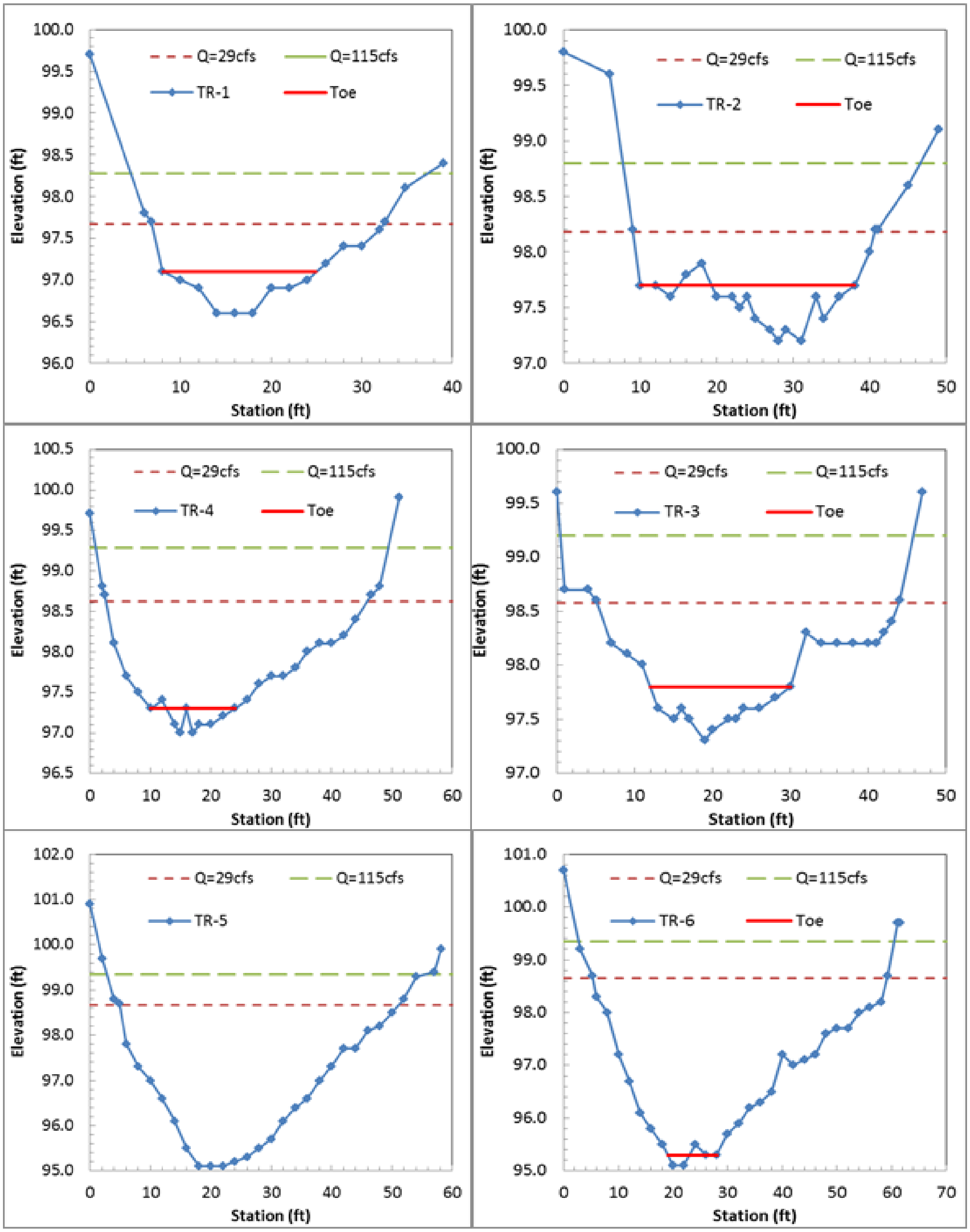
Rearing Life History Stages



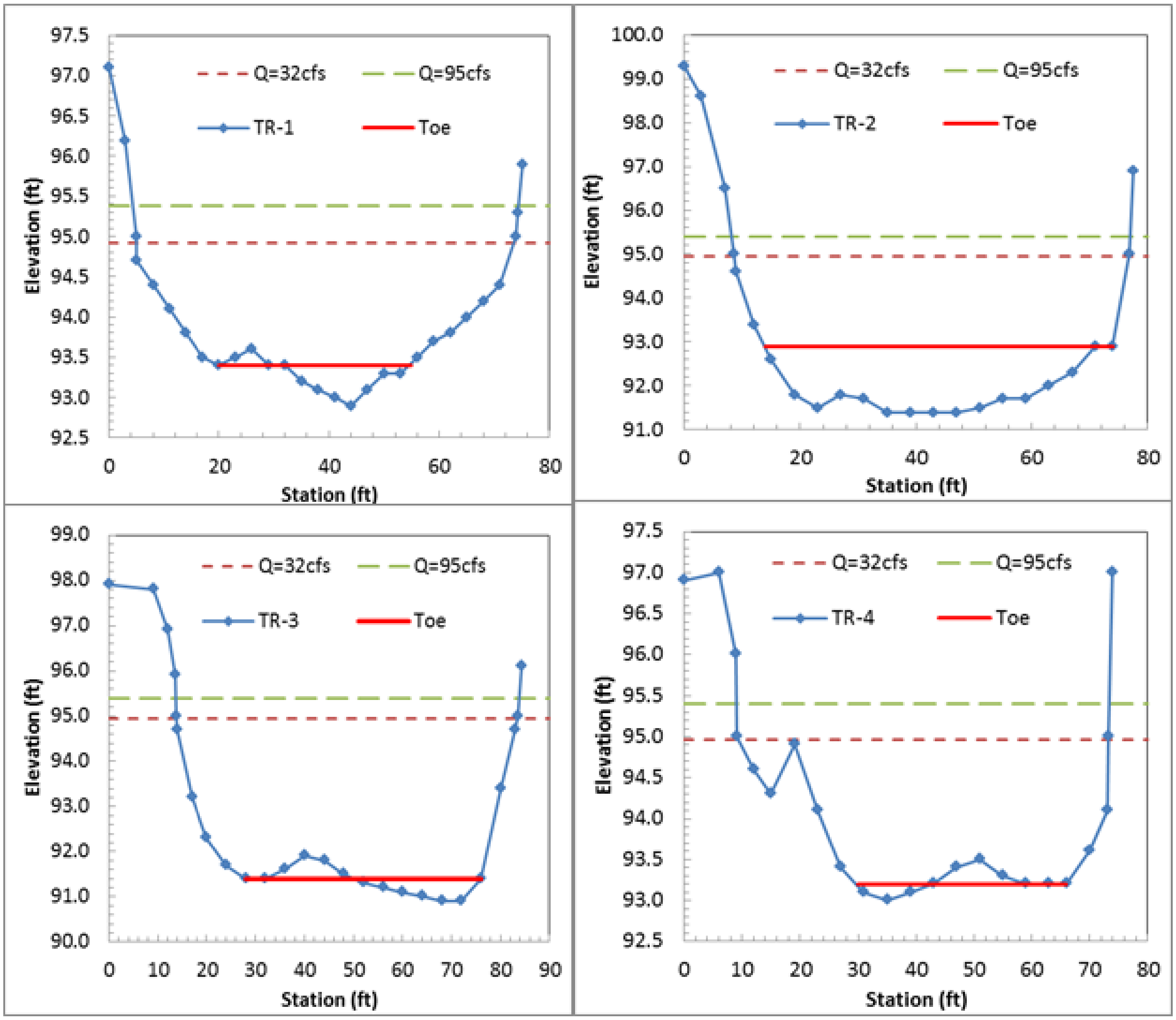


Appendix D – Toe-Width Relationships at Key Reaches.

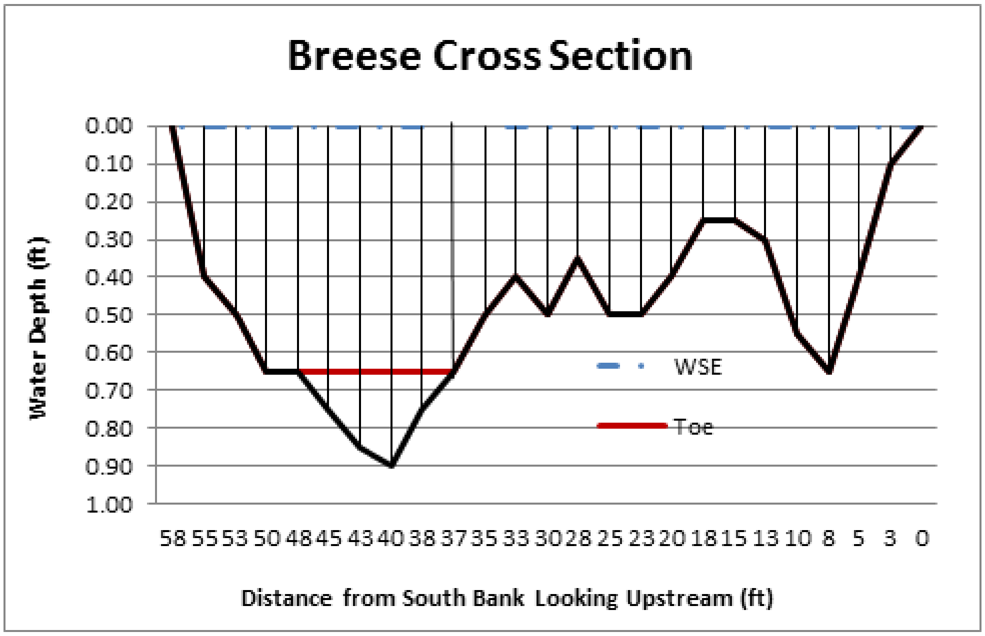
Prineville Valley (Hardin Segment 2) – Les Schwab Ball Field
Average of Transects = 37 ft.



Prineville Valley (Hardin Segment 2) – Quail Valley Ranch
Average of Transects = 75 ft.



Ochoco Creek – Breese Diversion



Whychus Creek – USGS Gage # nr Sisters, OR